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A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL HUMAN PERFORMANCE IN SYSTEMS VOLUME II

PART A

SYSTEM DEVELOPMENT ACTIVITIES CONCERNED WITH PUTTING MAN IN AN AEROSPACE SYSTEM

PART B

DEVELOPMENT OF MAN-MACHINE SYSTEMS: SOME CONCEPTS AND GUIDELINES

Prepared by

SERENDIPITY ASSOCIATES

Chatsworth, Calif.

for Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1968

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By Staff of Serendipity Associates

Prepared under Contract No. NAS 2-2955 by
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A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL
HUMAN PERFORMANCE IN SYSTEMS

Volume I

PART A

A SIMPLE MODEL OF A MAN-MACHINE DEVELOPMENT CYCLE

PART B

A SIMPLE CALCULUS FOR DISCRETE SYSTEMS

Volume II

PART A

SYSTEM DEVELOPMENT ACTIVITIES CONCERNED WITH
PUTTING MAN IN AN AEROSPACE SYSTEM

PART B

DEVELOPMENT OF MAN-MACHINE SYSTEMS:
Some Concepts and Guidelines

Volume III

AN APPROACH FOR DETERMINING THE OPTIMAL ROLE OF MAN
AND ALLOCATION OF FUNCTIONS IN AN AEROSPACE SYSTEM

Volume IV

A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL
HUMAN PERFORMANCE IN SYSTEMS
Final Summary Report

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FOREWORD

This report is, in a sense, an extension of the model presented in Report I. Part A presents more detailed information about the activities in the model which have to do with the aspects of system design that are directly related to man. Part B relates selected terms within all the research reports to the common vernacular of the biotechnology and system engineering community. The two parts are presented as essentially separate reports and are referred to as Report IIA and Report IIB throughout. The research was sponsored by the National Aeronautics and Space Administration, Ames Research Center, under Contract NAS 2-2955.

This effort was greatly enhanced through the interest and support of the technical monitor, Mr. Charles Kubokawa of the Biotechnology Division at Ames Research Center.

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DEVELOPMENT OF MAN-MACHINE SYSTEMS: SOME CONCEPTS AND GUIDELINES

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PART A

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System Development Activities Concerned with Putting Man in an Aerospace System: Activities Required for Obtaining Optimal Human Performance in Systems

All aerospace systems include man performance. Although man may not be included as an element of the flight segment, he is always employed in the launch segment. Therefore, in developing an aerospace system, as in the development of any system, care must be taken to put man into the system in a way that can be defended as "good." In the case of aerospace systems, however, the care which is taken has a "greater than usual" importance. In the flight segment, man takes up precious weight, power, and volume and his inclusion there must be justified in terms of overall system quality as the best use of that weight, power and volume. Further, the consequences of system failure when the flight segment is manned may be the loss of human life, and therefore human performance in both segments must be employed with care to assure the safety of flight personnel.

It is clear that there is a need to ensure that man is designed into aerospace systems in an optimal way. By this we mean that the system solution selected must employ man in a way that yields a highly desirable operational system in terms of overall quality and cost as compared with other system solutions within the state of the art.[1] Thus we emphasize that an optimal solution is one which is desirable as a <u>whole</u>; it is not one which has been suboptimized with respect to human performance or any other system part or subsystem.

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[1] In this series of reports we will speak of <u>an</u> optimum solution rather than <u>the</u> optimum solution. We do assume that there is at least one very best solution among all possible solutions for any given system problem. Sometimes the word optimum is used to denote this solution. We, however, assume that there are other solutions in the Cost, Quality neighborhood of the best one which are also highly acceptable. We take the position that finding <u>any</u> solution in this neighborhood will be satisfactory for the purpose of solving the problem which gave rise to consideration of the system to be developed. We will refer to any solution from this neighborhood as an optimum solution.

While it is one thing to say that an optimal system solution is needed, it is quite another thing to devise a development strategy that will produce one. For one thing, such a strategy must take account of when man-related actions are taken relative to the timing of other actions in the development cycle. The timing strategy should be such that decisions are made neither: (1) so late that prior related decisions force a poor one to be made, or (2) so early that the decisions exclude subsequent desirable decisions. Thus, in order to ensure that a development cycle will produce an optimal system solution, we must at least have a strategy for making design decisions which do not preclude the production of an optimal solution; preferably, we would choose one that would promote an optimal solution. A development cycle strategy to satisfy these requirements is presented in a companion report, Report IA, A Simple Model of a Man-Machine System Development Cycle. Report IA presents not only a symbolic version of a development cycle model, but it also presents the rationale for the model in order to provide for confidence in its use, and for its improvement by evolution.

While the model of Report IA places man-related development activities in context and includes a strategy for the relative timing of man-related decisions in development, it does not provide information needed for the design and control of each of the identified man-related activities. Report IA thus leaves a significant gap.

This report, Report IIA, is presented in response to the need identified above which is not satisfied by Report IA. It is intended to meet the need for an aid to planning and controlling each activity in an aerospace system development cycle which is related to the production of man-related end products such as trained personnel, job aids, human-engineered interfaces and so on. To achieve this objective, it presents detailed information about each man-related activity in the development cycle not given in Report IA. The purpose of each man-related activity is discussed in the context of the overall development cycle objective; dependencies upon other activities are identified; demands of other activities are identified; interactions among activities are called out; and an overview of the process of conducting the activity is given. The specific activities which are considered are identified in the overall model of an aerospace system development cycle that is set forth in Report IA. (See also chapter 3 of this report.)

The basic development cycle model which identifies the man-related and development activities is not appropriate for the purpose of identifying who will perform the activities, what equipments are needed, and what disciplines and data must be brought to bear in each activity. In fact, the basic model presented in Report IA is a "Go" model which does not take account of the technical management required to preclude, to detect, and to correct errors in the development cycle as it proceeds. It is in the description of the activities in this report that these matters are considered. Thus, in describing each activity, the "ideal" approach set forth in the model is reconsidered from a practical standpoint of what must take place in the real world of system development.

When we consider such things as the manning and equipage of the activities presented in the model, we find that the activities fall into natural groupings. Thus, we find in the real world that several different activities might be accomplished by essentially the same personnel using the same equipment. It is therefore convenient and natural to talk about these activities together, as a group. To reflect this feature of the real world of system development, the man-related activities identified in the model have been organized into activity groups. Each activity group is presented as a chapter and includes a prologue in addition to specific discussion of each of the activities in the group. The prologue to each group discusses the requirement for the activity group, the relationship of the group to that development cycle model, and the resources needed to implement the activities in the group.

Each activity description and each activity group discussion has been prepared in such a manner that it may be used without extensive referral to the descriptions of other activities and activity groups. The redundancies which result from this kind of approach make the report somewhat unsuitable as one to be read from cover to cover. However, the main objective of the report is to provide information useful in the planning and control of activities related to putting man in an aerospace system, and it is anticipated that when it is used for this purpose it will be used by persons primarily interested in a single activity group, or even in a single activity. Such users would find the report cumbersome if each activity group discussion were not designed so that it may stand alone except for reference to the overall model and assumptions. A symbolic version of the overall model is presented for easy reference in chapter 3. The assumptions and conventions employed throughout the activity group discussions are summarized in chapter 2.

Unless the reader is concerned with justifying the basic development cycle model which was used as a basis for identifying the activities discussed in this report, he may employ this report without referring to Report IA, A Simple Model of a Man-Machine Development Cycle. If the user is specifically interested in detail regarding those development cycle activities which relate to determining the role of man in an aerospace system, or which relate to identifying the functions to be allocated to man in an aerospace system, he will find it useful to refer to Report III, An Approach for Developing the Optimal Role of Man and Allocation of Functions in an Aerospace System. Report III is intended for use by human factors and biotechnological personnel who must carry out these kinds of activities within a specific aerospace system development cycle. The report contains detailed information about the decision processes involved and also presents supporting data needed to carry out the decision-making actions. Part B of this report, Development of Man-Machine Systems: Some Concepts and Guidelines, is intended for use by personnel who desire to understand the usage and implications of concepts commonly employed in talking about man-machine system development. Part B not only discusses common concepts and terms in the jargon, but also relates them to the concepts and terms chosen for use in Reports I, II, and III in this series.

II. BACKGROUND INFORMATION

To talk about the process of man-machine system development with reasonable precision by means of the words in common usage requires excessively frequent and tedious circumlocution. In Reports IA and IB, precise communication is signally important; therefore, a special vocabulary for talking about the system development process is presented in these reports. Many of the words in this vocabulary are also employed in this report simply because the ideas presented in the other reports are carried over to this one. Therefore, in this chapter we will present a discussion in which the key terms in the special vocabulary are introduced in a context that is designed to promote useful understanding of the concepts to which they refer. The attempt here is to minimize the discussion of these special words to the greatest extent consistent with the objective of obtaining a satisfactory understanding for the purposes of using this report. Readers should see Report IA for a more detailed exposition of the terms which are discussed in this chapter. Report IB provides an even more precise definition of some of the terms such as state, function, system, monitoring function, and partitioning, all of which are key terms in the calculus that is presented within that report. For most users of this report, the longer discussions in Reports IA and IB are not necessary.

Following the discussion below which introduces the special vocabulary, the symbolic portion of the development cycle model of Report IA is presented along with a brief discussion of it. Again, most users of the report will not find it necessary to refer to the lengthy presentation of the rationale underlying the model that is presented in Report IA.

Conventions and Assumptions

A basic term that will be used with great frequency is the term STATE. We will use the word state to refer to the symbolic statement which results from carrying out an act of measurement at a point in time. Thus, whenever a properly trained person makes a measurement of the real world using a procedure which is defined and which can be used by any other properly trained person, the result is a symbolic statement (for example, "two meters") which may be thought of as being in correspondence with some attribute of the real world at the time of measurement. Properly, we express a state by noting the time of measurement, the method of measurement employed, and the results of carrying out the measurement. In practice, we ordinarily write down only the results of the act of measurement leaving the reader to infer the act of measurement and the time.

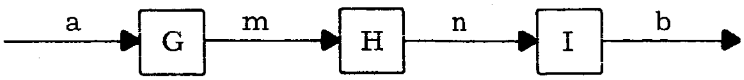
We use the concept of state to define the concept of FUNCTION. Roughly speaking, a function is a pair of states in which the second state occurs later in time than the first with a probability in the interval $0 < p \leq 1$, given the first state. The first state is called the INPUT STATE of the function, and the second is called the OUTPUT STATE of the function. It should be noted that the definition of function does not include any reference to a real world MEANS by which the function is to be implemented. Thus, a function is a symbolic expression in terms of input and output states and probabilities. Being unbiased, it permits us to find as many means as possible by which the function might be implemented. When we speak of a means that can be used to implement a function, we refer to a real-world process or thing which can be set in correspondence with the function such that when acts of measurement are performed on the means, the input state of the function is obtained, and the output state is obtained with the probability given in the function definition.

In the system calculus underlying these concepts (see Report IB), PARTITIONING and ADDING are defined rigorously. It is useful to have a working understanding of these concepts. In everyday work we will denote a function, F, by arrangement of "boxes and arrows" as shown below.

$$\xrightarrow{a} \boxed{F} \xrightarrow{b}$$

$$P_b = q, \text{ given } a$$

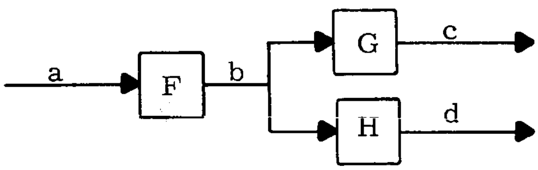
Again roughly speaking, an array of functions whose first input state and whose terminal output state are the same as those in the function given above is said to be a partitioning of that function. For example, the array of functions shown below is a partitioning of the function given above.



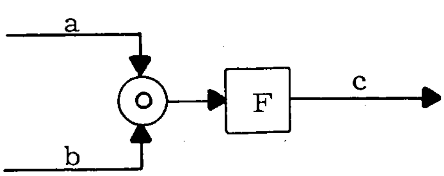
P_b = q, given a

When the COMPONENT FUNCTIONS G, H, and I in the array of functions given above are added together, we obtain the original function, F. Adding is thus the inverse of partitioning.

When the output state, b, of a function, F, is distributed to two other functions, the OUTPUT STATE DISTRIBUTION is denoted in the following manner:

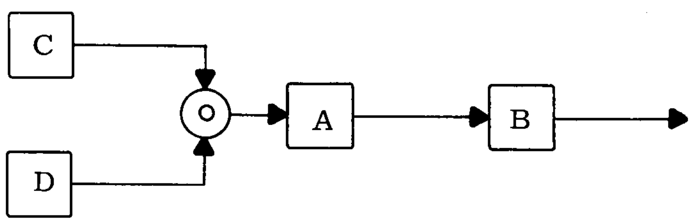


Sometimes the input state to a function is compounded of two or more states which are the outputs of separate preceding functions. The case in which the input state of a function includes two simultaneous output states a and b is denoted in the following manner by the AND symbol (O) :

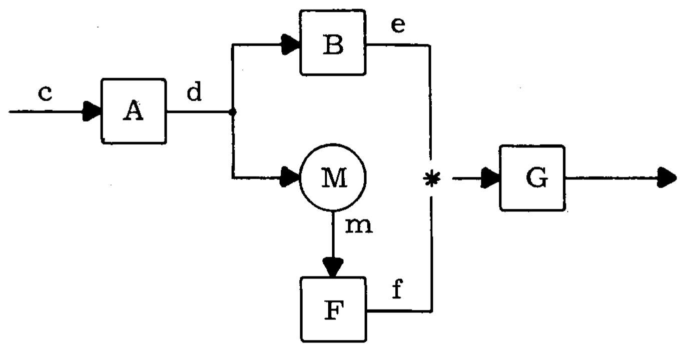


Note: The input to F is a <u>and</u> b. Neither a alone, nor b alone is an adequate input state.

Thus far we have avoided the use of the word SYSTEM; instead we have employed the word function. In these reports we reserve the word system to refer to a special kind of function. We use the word system to refer to that function in a given discourse which comprehends all of the other connected functions in the discourse. The function which can be obtained by adding all of the other connected functions in the discourse is thus called the system. We also employ the word system to refer to any array of functions whose initial input state is the initial system input, and whose terminal output state is the same as the system output state. Finally, we use the word system also to refer to any collection of means which can be set in correspondence with an array of functions which describes a complete system in the sense of a symbolically defined system. From time to time we will speak about special types of systems. Thus we will refer to FOLLOW-ON SYSTEMS and to ADJACENT SYSTEMS. Let us consider the system A in the diagram below to be the object of concern in a given discourse. Then the system B which receives its output (or more properly which demands its output) will be called a follow-on system. Systems C and D which are also directly related to it will be called adjacent systems or, more specifically, adjacent input systems. When we talk about the collection of means which implements system A, usually it will be necessary to talk about other types of adjacent systems as well. Thus, the systems in the environment of system A hardware which are affected by its spurious outputs will also be called adjacent systems.



Usually when we talk about man-made systems, we are concerned with the overall probability of success of the system. Usually a target with high probability of system success cannot be achieved without the use of MONITORING FUNCTIONS. Monitoring functions are functions which respond to the absence of a desired output state. Such functions can be used to "turn on" back-up functions, or corrective functions, so that the desired output state can be returned to an in-tolerance condition. A monitoring function is denoted in a schematic system diagram by a large circle. In the diagram below the function M is a monitoring function.



* e or f will occur, but not both. Either is an input state of G.

In the above diagram the sequence of functions M, F provides an output state which may be employed by system G in lieu of the output state of function A. Because the monitoring function M responds only when the output of function A is out of tolerance or absent, this sequence of functions acts to restore an input state to function G in a manner which increases the probability that the output of function G will occur. The sequence of functions M, F is called an ADDITIVE LOOP. Any sequence of functions which is initiated by a monitoring function and which acts to increase system probability of success is called an additive loop. Usually a system which must have a high overall probability of success incorporates many additive loops. The collection of all additive loops is called an ADDITIVE SET. Some of the additive loops in an additive set may be implemented by means of redundant hardware, some may be implemented by means of corrective maintenance, some by preventive maintenance.

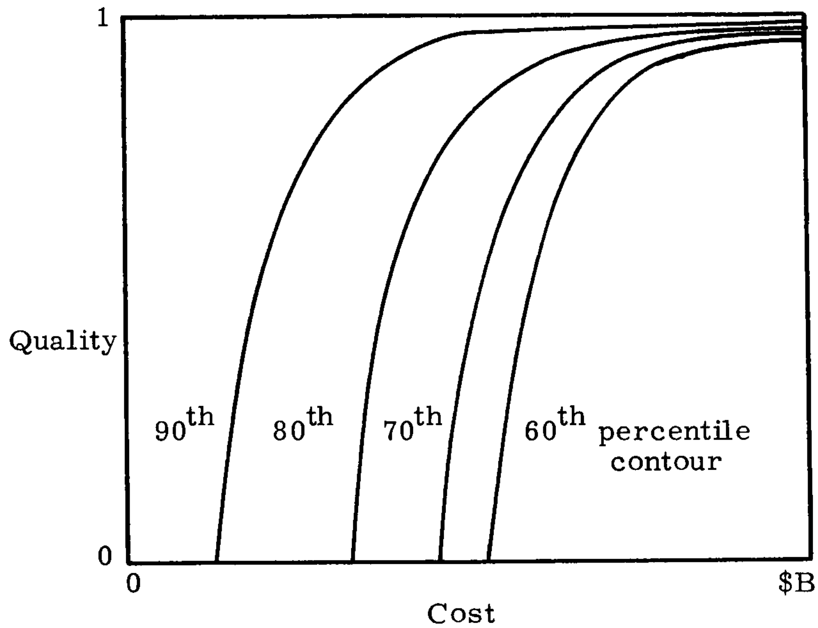
An array of functions which is a system is called a PRIME SYSTEM if the array contains no additive loops and if every function in the array is essential to the achievement of the system output. At the heart of every system there is a prime system whose probability of output is greater than zero.

In these reports, we are concerned with the process of aerospace system development. A basic idea underlying the treatment of this process is that the development process may be described as a system. When we treat the development process in this way, the input state is called a PRIMITIVE NEED STATEMENT. This statement, which initiates the process of development, is any statement which calls attention to a problem or need in the real world and which eventually leads to the design, development, and operation of a system to solve the need or problem. The output of a DEVELOPMENT CYCLE conceived as a system is an installed operational system that is capable of satisfactorily solving the need which gave rise to its development. The need to be satisfied is associated with a follow-on system to the system that is built. The principal agency responsible for the follow-on system is called the CUSTOMER. The customer is not necessarily the person or agency who provides the funds for building a system that is required to solve his problem. However, because the customer is responsible for the follow-on system, he places demands upon the system to be built by identifying the input which he requires. The input which is so identified is the desired output state of the system that is to be built.

The output of a development cycle is called an OPERATIONAL SYSTEM. Thus, a development cycle produces all of the means necessary for there to be an operational system. It is the output of the operational system that is the desired input to the follow-on system of the customer. The desired output of the operational system is described by means of a QUALITY SCORE FORMULA. This formula, which expresses the requirements of the customer, tells how the output of the operational system should be measured and what score should be obtained when it is measured. A Quality score formula thus provides one basis for describing how the "goodness" of the operational system should be measured. A Quality score formula measures the goodness of a system without regard for the means by which the system is implemented. Therefore, it does not take into account the ways in which a given system solution affects other systems in its environment by spurious outputs and by the inputs which it demands. In most cases, given a Quality score formula and a TARGET QUALITY SCORE, it is possible to construct many different physical systems that will yield the desired quality score. Some of these physical systems will have very undesirable side effects, however, and will have to be rejected because of these side effects. For example, a candidate physical system may contribute toxic contamination to the air, to the ground, or to the water, and thus be completely unacceptable. Other system solutions may make undue demands upon adjacent systems which cannot be met. For example, a system solution designed to achieve a given quality score according to a given Quality score formula may demand input power that is simply not available. The scoring of a SYSTEM SOLUTION (that is, of a specific collection of means for achieving a given quality score) must take into account the relationship of the solution to its environment. This accounting is done according to an "A" SCORE FORMULA which results in an "A" score for the system. "A" score formulas are specific to system solutions; they do not apply generally to all system solutions as do Quality score formulas. Both the "A" score of a system and its quality score relate to what might be called the "goodness of the system."

Just as all system solutions may be compared on the basis of quality scores, so may all system solutions be compared on the basis of COST. By cost, we mean the totality of all of the resources necessary to design, develop, fabricate and install, operate and maintain a physical system that will satisfy a need of concern. However, if we are to compare alternative system solutions in terms of cost, there must be a formula for computing cost, so that cost will be computed in the same way for all systems to be compared.

Now it can be seen that any system solution has a cost, a quality score, and an "A" score. It can also be seen that all system solutions for a given problem can be compared on the basis of quality and cost in common terms.[1] Because all system solutions for a given problem can be measured according to the same quality and cost formulas, all such system solutions occupy a common COST, QUALITY SPACE. We may schematically denote such a Cost, Quality space in the following manner.



In the above diagram, the contour lines (growth curves) are intended to show that the density of system solutions is not the same throughout the Cost, Quality space. There are more system solutions of low quality and high cost than there are of high quality and low cost. The contour lines show how the density falls off in the given Cost, Quality space. In general, it is the

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[1] We have already shown that the "A" score of the given system solution is idiosyncratic, making it impossible to compare a number of different system solutions on common grounds in terms of "A" scores.

objective of the first phase of a system development cycle to make certain that phases II and III (the design and fabrication phases) will be directed toward acquiring a physical system which is reasonably high in quality and reasonably low in cost in comparison with the other solutions to be found in the Cost, Quality space.

Two systems of the same cost and the same quality are not necessarily equally suitable. One of the two systems may have a very bad effect upon its environment as reflected in its "A" score, whereas the other system may have no appreciably bad effects. To preclude the design and fabrication of a system with inordinately bad effects upon the environment which could have been avoided by the application of good engineering, it is common to place CONSTRAINTS upon a design and development program. Constraints are statements which place limitations upon the degree of freedom of the designers for the purpose of ensuring that processes are not employed in the design which will give the system an unacceptable "A" score.

To provide for control over the process of system design and fabrication, and to ensure that all steps in design and fabrication are directed toward a common goal, it is desirable to describe that goal in terms of the manner in which measurement will be carried out to determine whether or not the goal has been achieved. The document which sets forth the manner in which goal achievement will be measured at the end of a development cycle, and which, therefore, also tells how steps toward goal achievement will be evaluated, is called a BASIC SYSTEM SPECIFICATION. A Basic System Specification must set forth the Quality score formula, a target quality score, a costing formula and upper limit of cost, an "A" score formula, and identification of the conditions under which the physical system that is fabricated will be measured to determine its quality, cost, and "A" score.

Within the Quality score formula that is contained in the Basic System Specification there will virtually always be provision for measuring SYSTEM PROBABILITY OF SUCCESS (probability of output of the system that is desired). Probability of success is of signal importance in the case of aerospace systems in view of the penalties of system failure: large dollar loss and loss of human lives. We will speak of the requirement for probability of success, and to achieve it we will select means which are RELIABLE. Thus, reliability is an attribute of means by which probability of output or probability of success goals are achieved. We will not talk about the reliability of men in the system, but we will talk about the reliability with which component functions in a system are performed by man. Thus, probability of output is always associated with functions, and reliability is always associated with means that are in correspondence with specific functions; it is not useful to talk about the general reliability of a general purpose means.

We have injected the term AEROSPACE and it is necessary to define it. An aerospace system is an operational system with a LOCAL (flight) SEGMENT and a REMOTE (launch or base) SEGMENT. The remote and local segments are physical packages which are configured so that the local segment can move through space relative to the remote segment. These segments operate together as a system defined by a single Quality score formula. An aerospace system always includes a propulsion function, and when the local segment (the flight segment) is manned, it always includes a PERSONNEL SUPPORT SYSTEM. The remote segment is always manned.

Personnel support systems are important elements in any aerospace system. The personnel support system in the flight segment is called a HUMAN SUPPORT SYSTEM. It provides the conditions necessary to obtain reliable human performance of functions assigned to man in the flight segment. The human support system typically includes an environmental control system, a life support system, and all of the facilities necessary to maintain living conditions necessary to the mental and physical health of the personnel aboard the flight segment. At the remote base segment, a personnel support system is referred to as a SAFETY AND SUPPORT SYSTEM. This system is concerned not only with providing for the health and safety and working conditions necessary for operator and maintenance technician performance, but it is also concerned with providing for a good "A" score when the "A" score formula demands attention to the effects of the system upon humans in its environment.

The concept of a personnel support system is that it must provide the environment necessary to realize the reliability of means. When we take into account what a means will be called upon to do and how reliably it will do that, we may speak of the PERFORMANCE CAPABILITY of the means. The performance capability of a means must always match the demands placed upon it by the definition of the function which it implements.

The model of an aerospace system development cycle that is presented in the next section is a "GO" MODEL. It is a functional design of a prime development cycle (development system). The model does not take into account what must be done to ensure that the development process will be carried out on time, within resources, and with high probability of success. All of these factors, however, are important in the measure of goodness of a development cycle itself. We call the measure of goodness of a development cycle DEVELOPMENT QUALITY (Dev. Q). It is analogous to the measure of goodness of the operational system in terms of quality. The quality of the system that is produced is itself an element in Dev. Q. To provide for a high Dev. Q, it is necessary to elaborate the "Go" model by the addition of MANAGEMENT FUNCTIONS. Some management functions must be added to provide for high probability that the development cycle will produce a high quality system. These management functions will be referred to as TECHNICAL MANAGEMENT FUNCTIONS. Other management functions must be added to ensure that the development cycle itself will be prosecuted on time and within the money available. Management functions of this type are referred to as GENERAL MANAGEMENT.

The end product of a development cycle which is properly managed is an operational system of the desired quality and cost. In the case of all aerospace systems, this end product will include what is called a PERSONNEL PRODUCTS PACKAGE. That is, it will include means which fall into one of the following five categories:

1. Selected and trained crew members;
2. Job aids;
3. Materials to maintain reliability of crew performance on the job;

4. Products of human engineering including interface devices, tools, and work space arrangements;
5. Personnel support systems (Human Support System and Safety and Support System).

Taken together, we will refer to all of these end products as a personnel products package. At the heart of the package will be selected and trained crew members who are capable of maintenance technician performance and operator performance as called out and allocated to them in the design of the system. The other categories of end products are required only because man is required, and they are thus secondary to the decision to include man to carry out essential system functions. Those functions which are assigned to man and which are prime system functions are referred to as operator functions and they are implemented by means of OPERATOR PERFORMANCE. Other functions which are components of additive loops are called maintenance technician functions and they are implemented by means of MAINTENANCE TECHNICIAN PERFORMANCE. The term "operator" is not used inasmuch as it implies a crew member who is assigned only operator performance. This option is seldom justifiable in the design of any aerospace system.

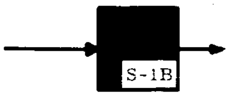
An Overview of the Development Cycle Model

The symbolic representation of the development cycle model presented in Report I is presented in this report in Figures 1 through 9. Figure 1 presents an INDEX MODEL which is a simplified representation of the complete model in terms of eight sequential functions. Each of the following figures (Figures 2 through 9) presents a partitioning of one of the functions in the index model. The component functions in each of these more detailed figures are referred to in the text as ACTIVITIES. Examination of Figures 2 through 9 will show that the major detail in these figures is focused upon activities concerned with the design and fabrication of personnel products. These figures are useful mainly for the purpose of showing the relationship among activities in the development process. The output states of each activity will be discussed in more detail in the chapters which follow; relatively little output information is shown in the figures to avoid complication of the diagrams.

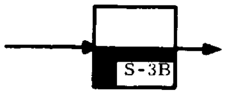
To Activity X

From Activity X

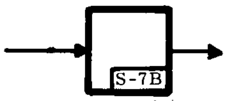
And symbol



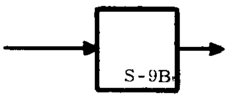
Activities concerned with dividing a system description to the segment level and with the integration of segments into a complete system.



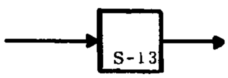
Activities concerned with dividing a segment into packages and with the integration of packages into segments (remote or local).



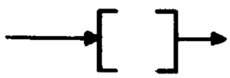
Activities concerned with dividing packages into first-order component packages and with integrating these into packages.



Activities concerned with dividing first-order component packages into second-order component packages and with integrating these.



Activities concerned with second-order component packages.



Hardware activities, not detailed.

Q	=	Quality
C	=	Cost
Dev. Q	=	Development Quality
"A"	=	Adjacent System
B.S.S.	=	Basic System Specification
H.S.S.	=	Human Support System
S.S.S.	=	Safety and Support System

Legend for Diagram Symbols and Notations

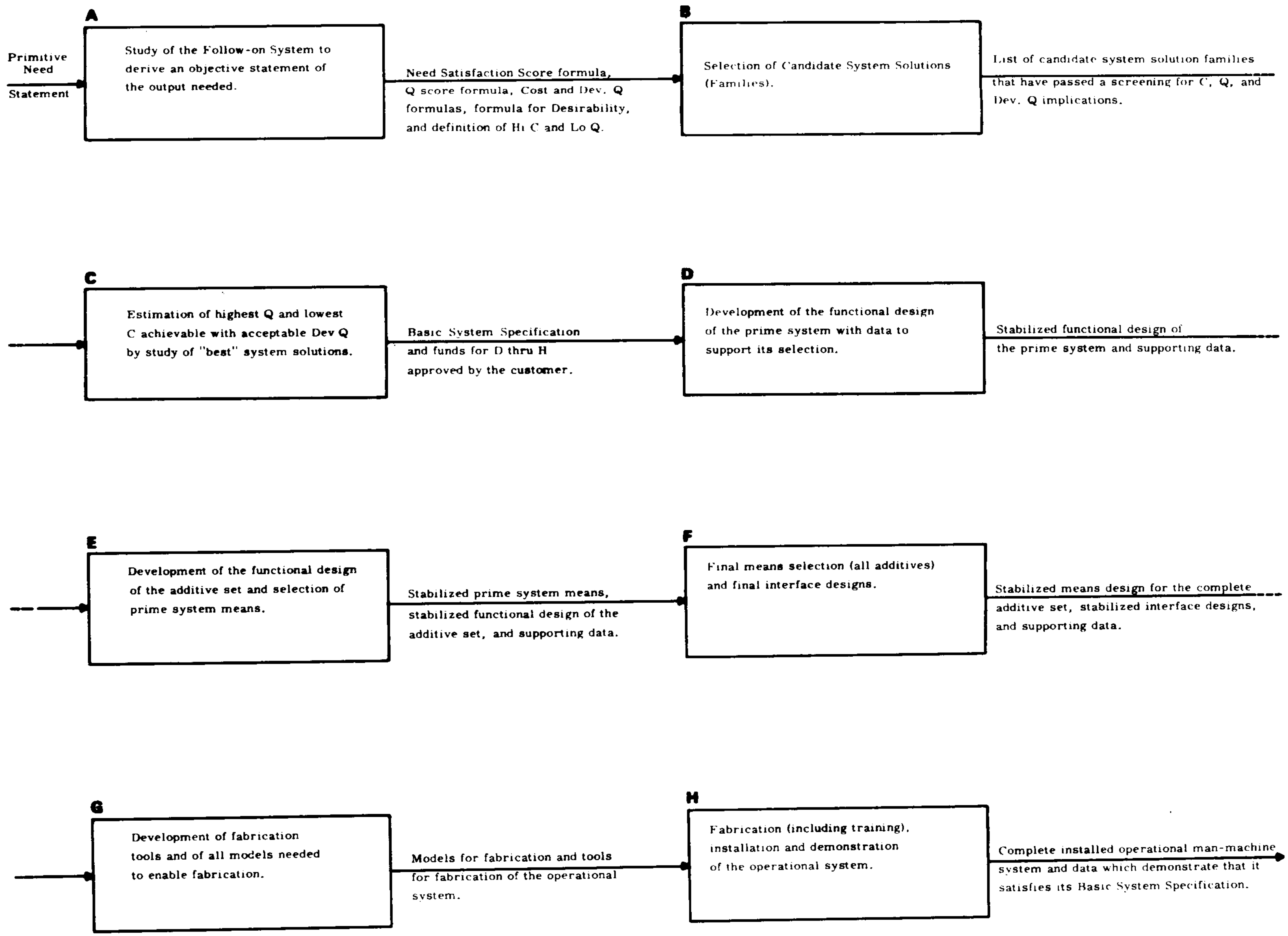


Figure 1. Schematic representation of the index model.

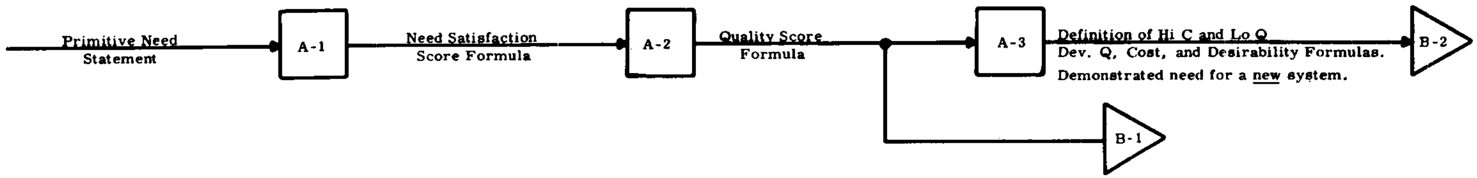
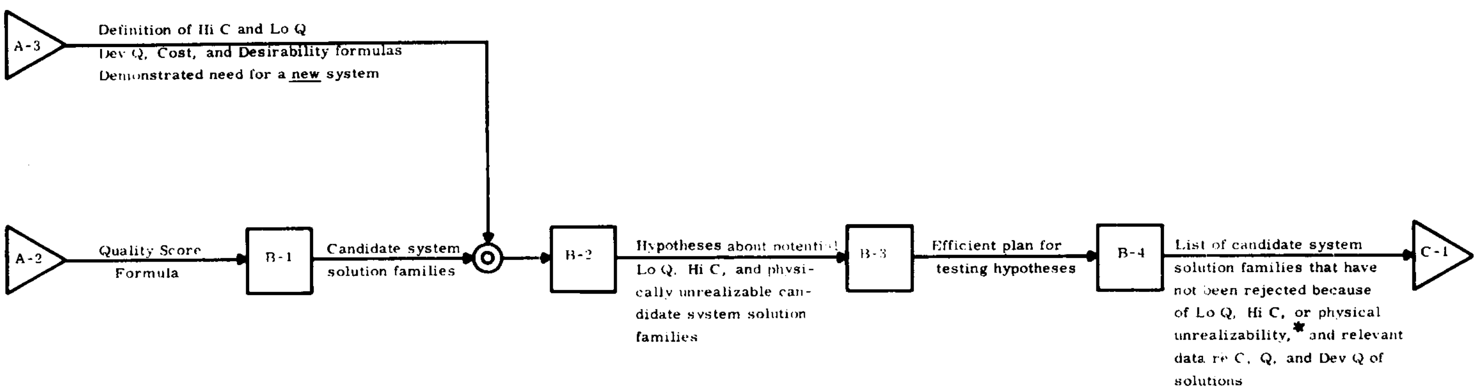
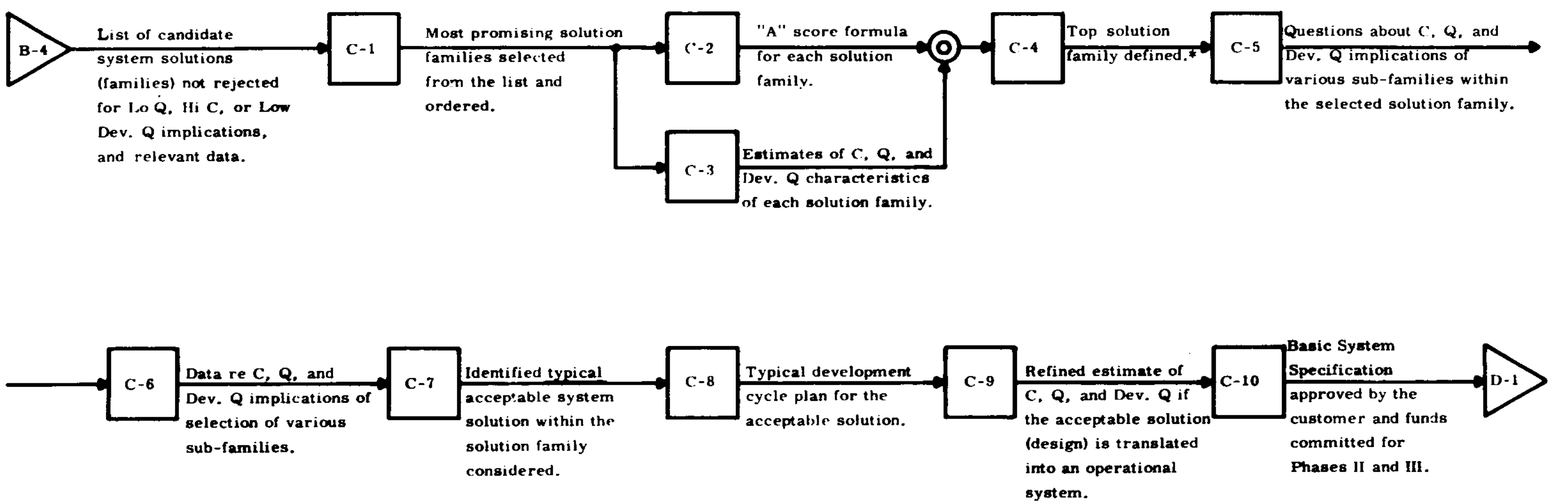


Figure 2. Diagrammatic overview of Function A (Phase I) showing the component activities and their relationships.



* Note: The type of activity sequence exemplified by B-2, B-3, B-4 may be repeated several times in order to shorten the list of candidate solutions sent to C-1. On the other hand, this sequence may be bypassed altogether if the output of B-1 does not need screening.

Figure 3. Diagrammatic overview of Function B (Phase I) showing the component activities and their relationships.



* **Note:** If it is desired to explore the Cost, Quality space adequately in Phase I, it will be necessary to identify several "top" solution families and to carry out parallel studies by replicating Functions C-5 through C-9 for each family. Such an approach would require comparison of the data for each family in C-10 as a basis for preparing the Basic System Specification.

Figure 4. Diagrammatic overview of Function C (Phase I) showing the component activities and their relationships.

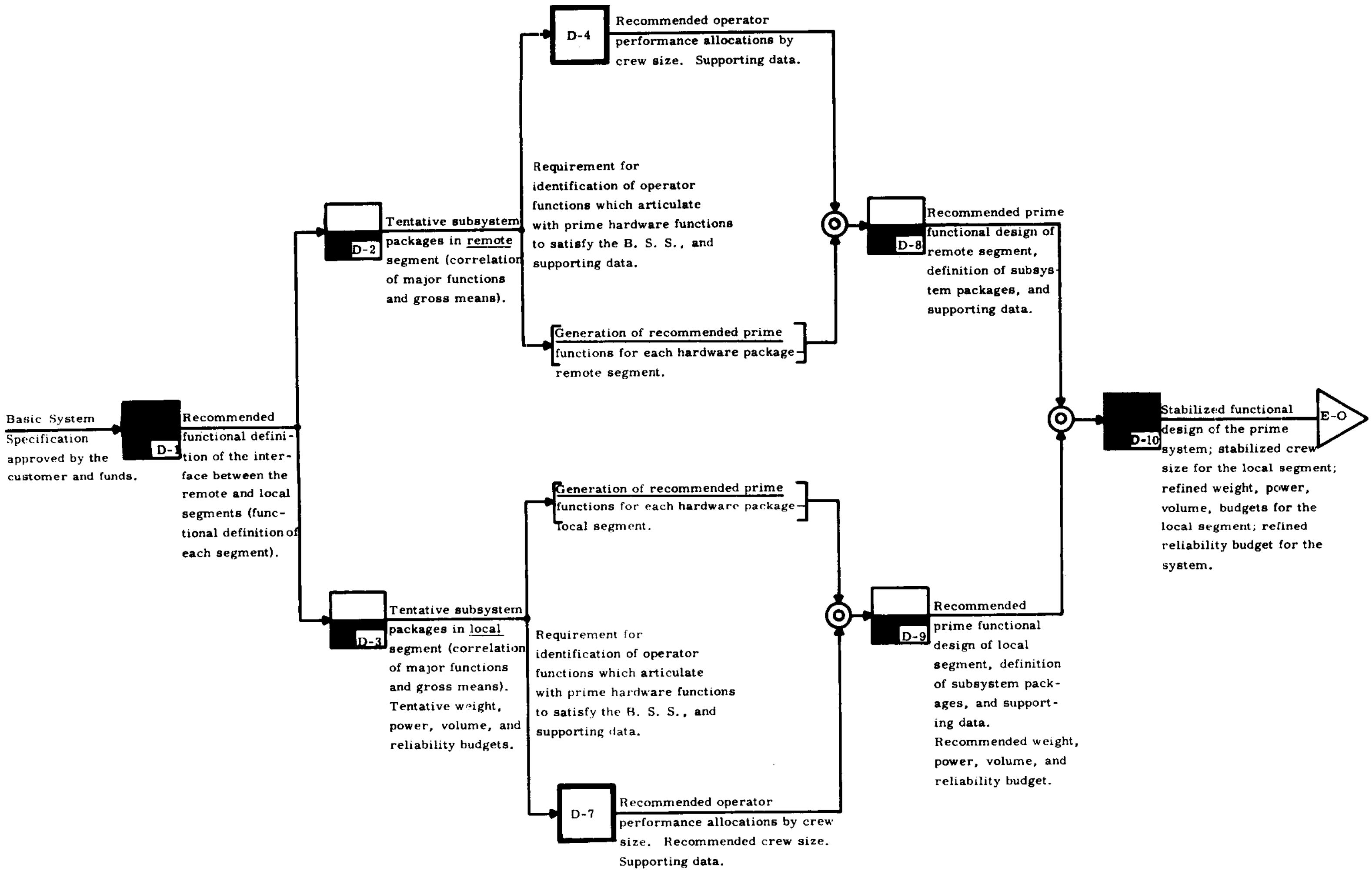


Figure 5. Diagrammatic overview of Function D (Phase II) showing the component activities and their relationships.

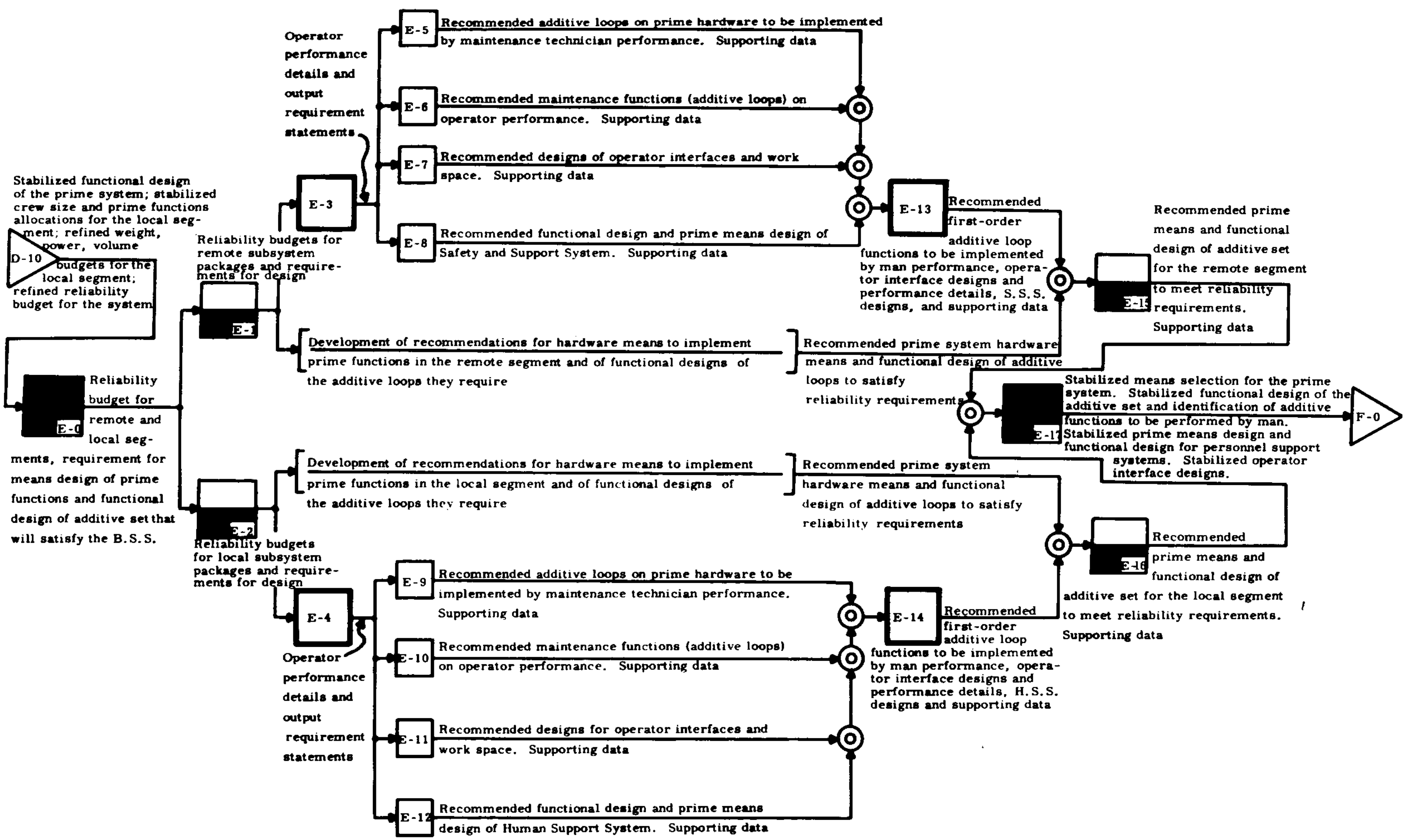


Figure 6. Diagrammatic overview of Function E (Phase II) showing component activities and their relationships.

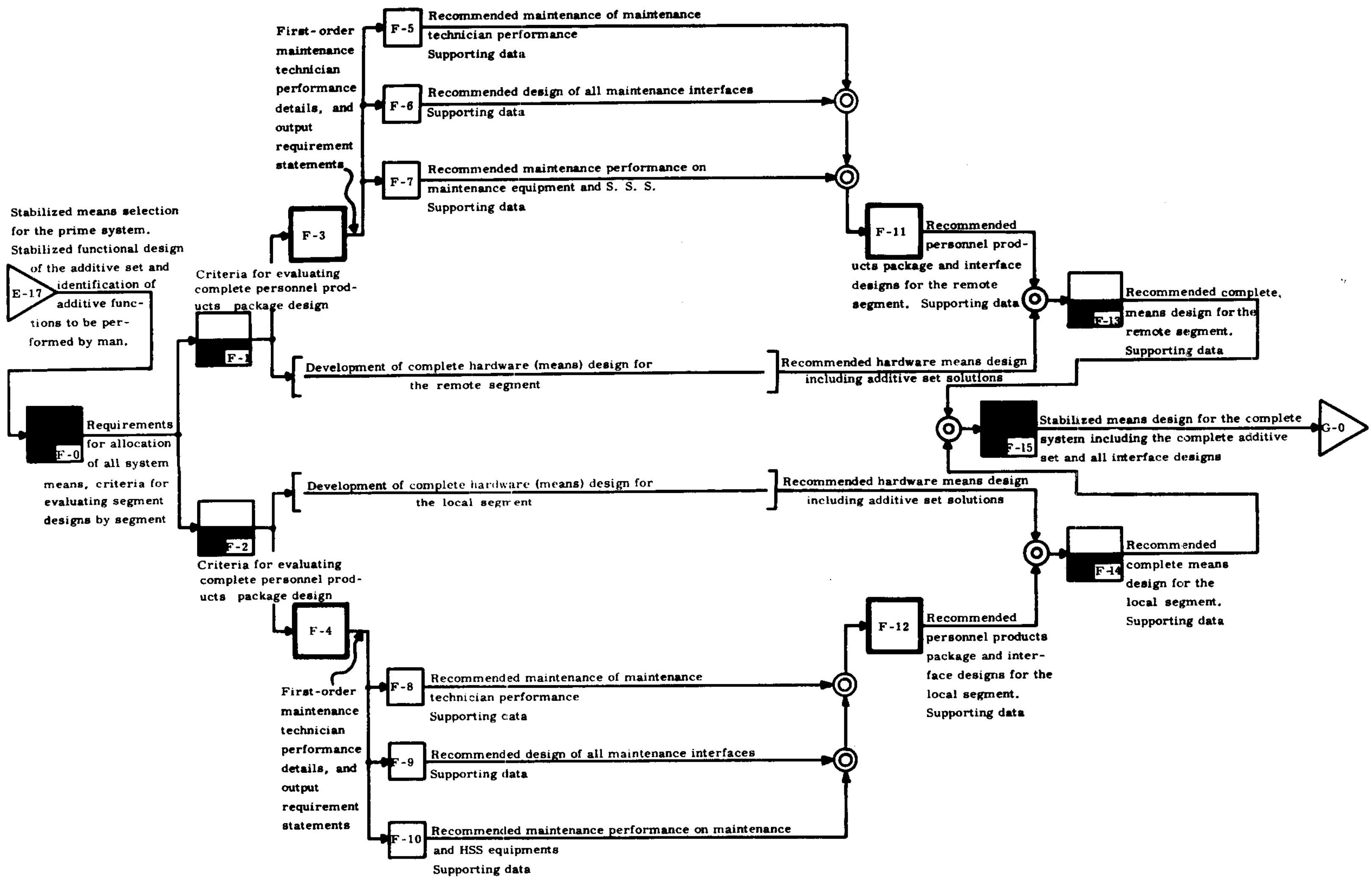


Figure 7. Diagrammatic overview of Function F (Phase II) showing component activities and their relationships.

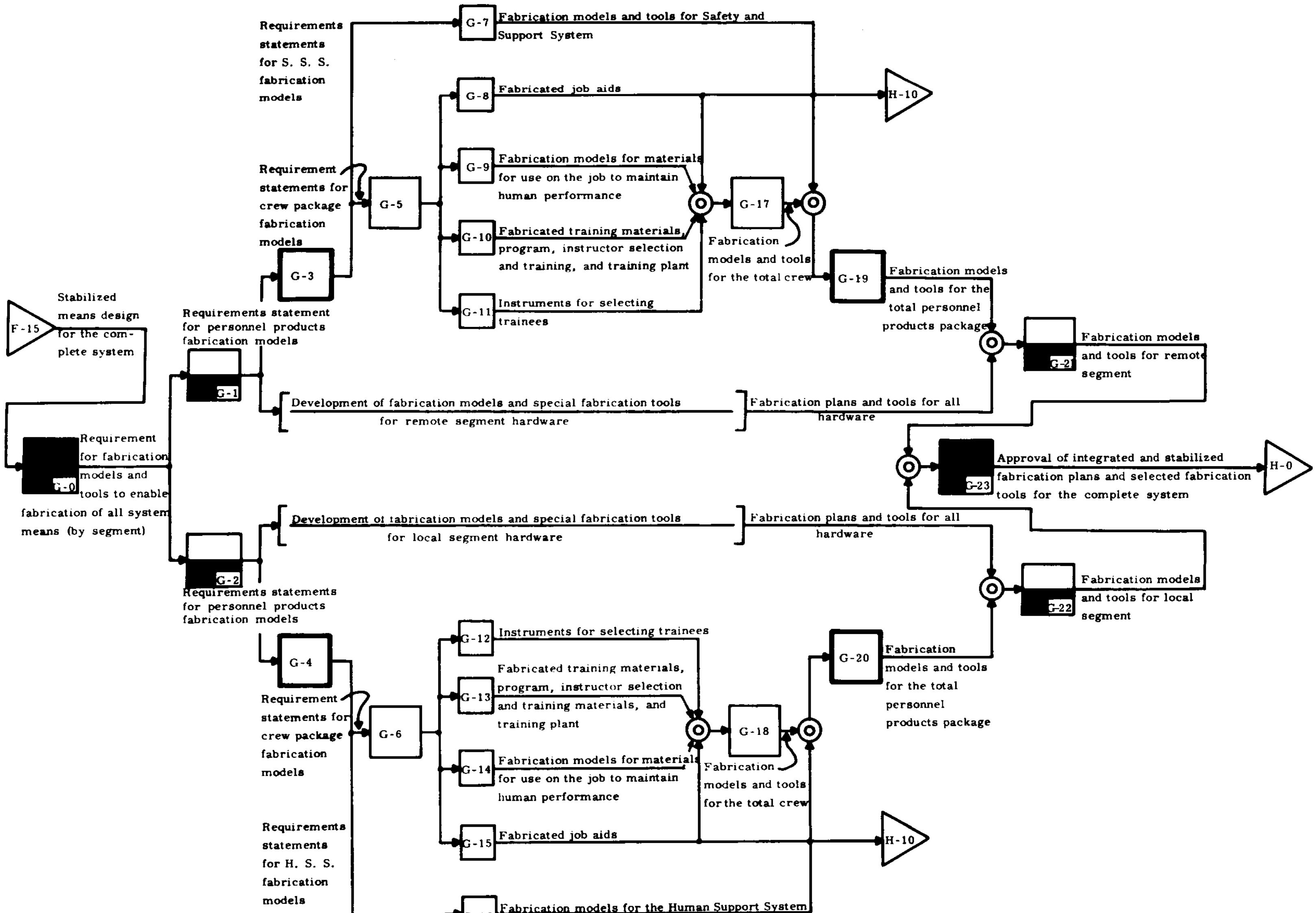


Figure 8. Diagrammatic overview of Function G (Phase II) showing component activities and their relationships.

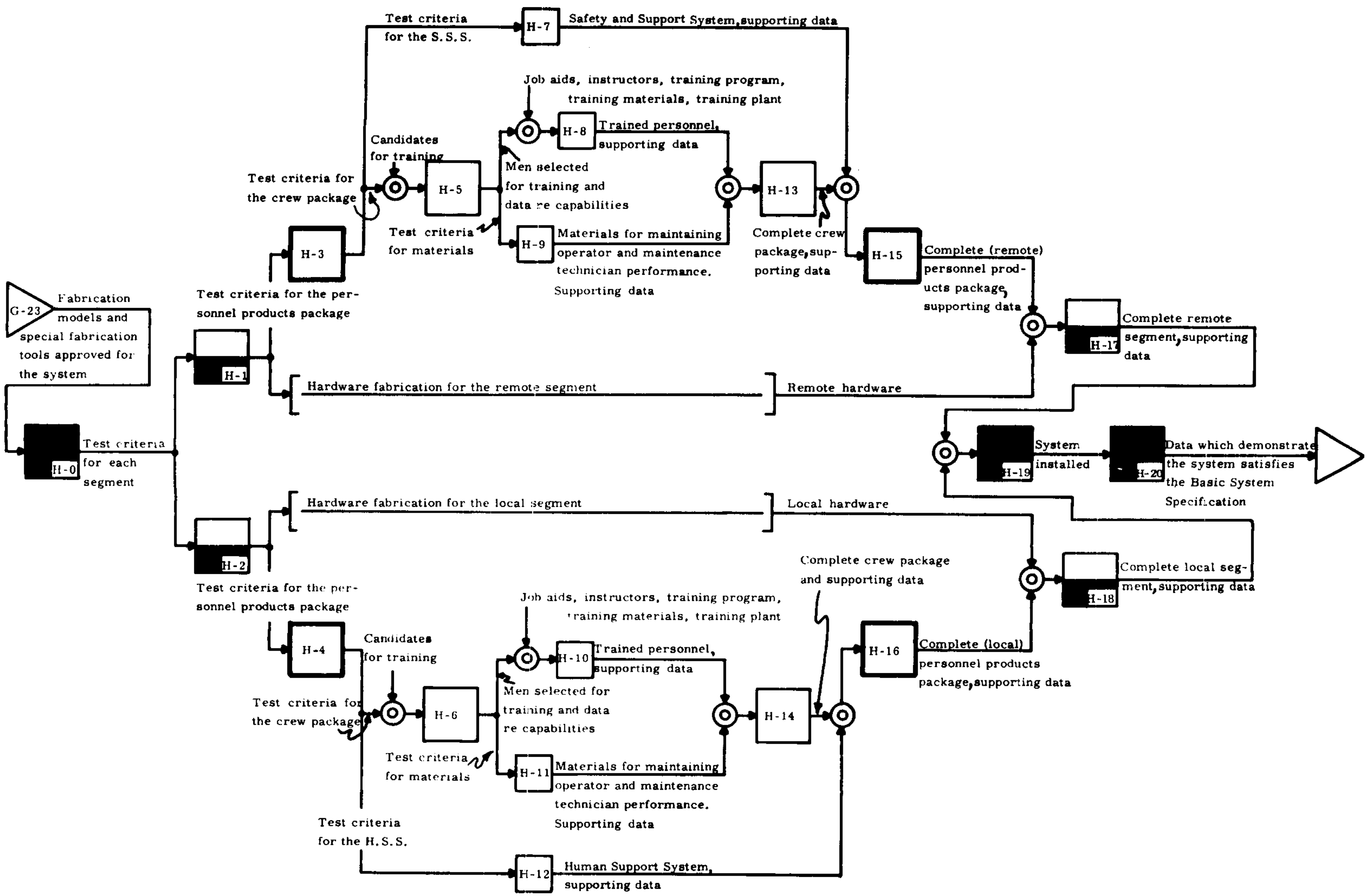
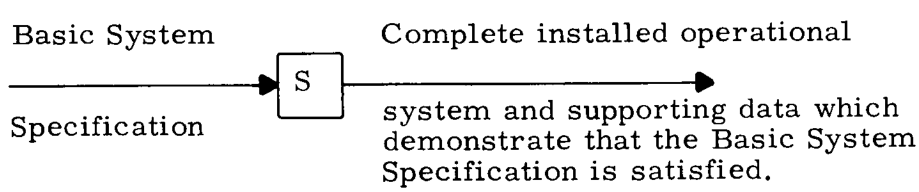


Figure 9. Diagrammatic overview of Function H (Phase III) showing component activities and their relationships.

Functions A, B, and C in the index model are discussed in Chapter III. It will be useful here to discuss briefly Functions D through H in overview. Functions D, E, F, and G taken together will sometimes be referred to as PHASE II, and Function H will sometimes be referred to as PHASE III. Functions A, B, and C constitute PHASE I. Phase II is initiated by a Basic System Specification; it is terminated with the presentation of a complete set of fabrication models — that is, a complete set of all of the engineering drawings, wiring diagrams, assembly instructions, and so forth, necessary to enable fabrication of the physical system. The output of Phase II is the input to Phase III which is concerned with fabrication. The output of Phase III (Function H) is the output of the complete development cycle; a fabricated, installed, and demonstrated operational system.

The rationale underlying the use of the Basic System Specification is employed over and over again in the partitioning of Functions D, E, F, G, and H and it will therefore be useful to consider that rationale. Fundamentally, the Basic System Specification is a test specification. It describes a complete and objective test by which the operational system as a whole may be evaluated, and it identifies what is meant by a "passing grade." When the Basic System Specification is conceived in this way, then we might represent Functions D through H as a single function, S , as shown in the sketch below.



In the diagram above, the function that is obtained by adding Phases II and III is bounded on the input side by a test specification and on the output side by an end product and data which demonstrate that the delivered end product has passed the "test." It is this pattern which is the characteristic pattern that will be employed over and over again in the full development cycle model — a pattern of specifying or "ordering" a piece of work by means of identifying the test which it must pass and then of bounding the output by a delivered end product plus data which show that it has passed its test.

In order that every design and fabrication activity at every level of detail in the model may be directed toward a specific and justifiable goal, the principle of specification by means of disclosing the test of the end product is employed throughout. To ensure that the tests are relevant, provision is made for all test specifications to be derived in an orderly manner from the overall system Quality score formula. No arbitrary tests which cannot be shown to be predictive of effects upon Quality have been introduced.[1] Provision for ensuring that all tests are related to Q is made by deriving all tests of system parts and subparts in an orderly progression from the overall system Quality score formula.

In order to exemplify the manner in which component Functions D, E, F, G, and H are partitioned in the full model, we will temporarily ignore the fact that Phases II and III are partitioned into these five functions and treat Phases II and III as a single function as symbolized in the schematic representation of Function S above. The partitioning of this function that we will develop will be typical of the partitioning of Functions D, E, F, G, and H in the full model.

The pattern in which Function S is partitioned is determined by the fact that aerospace system fabrication efforts are organized about physical packages. Fabrication efforts are not organized such that each subeffort corresponds to a specific system function, nor are fabrication efforts organized about specific technologies such as pneumatics, hydraulics, mechanics, and

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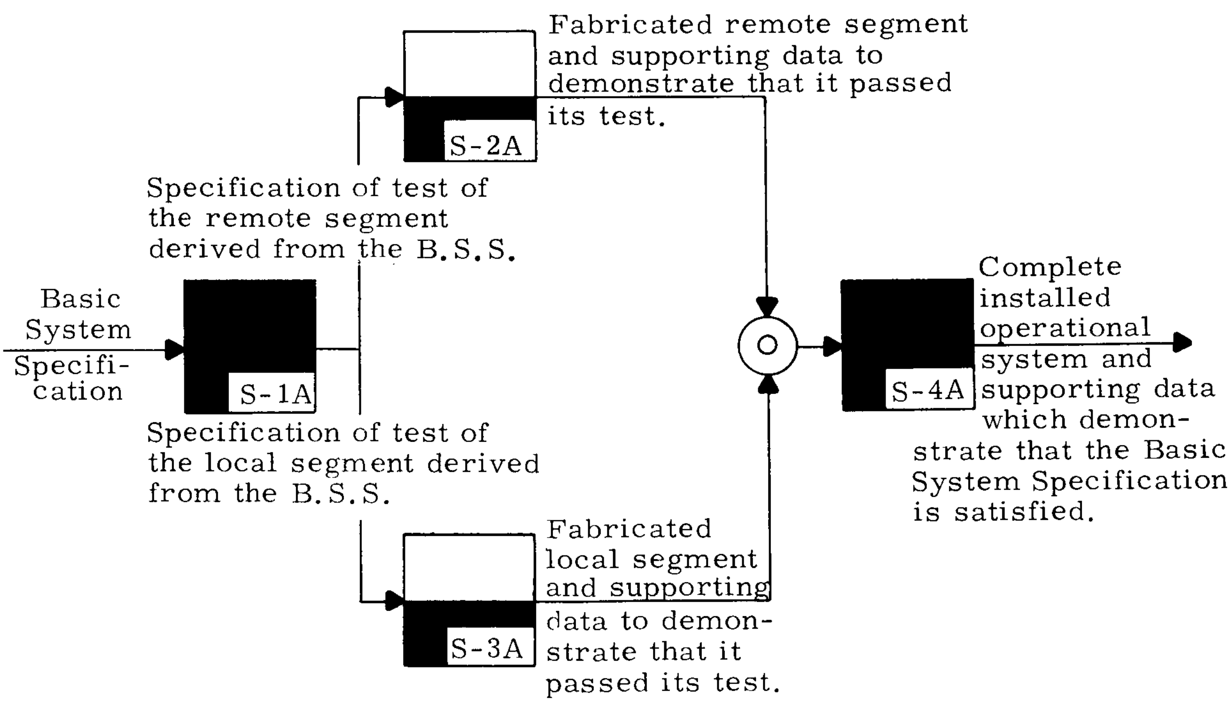
[1] The model does not identify specifically all ways in which the "A" score formula must be taken into account in the development process. All tests for quality within Functions D through H must include consideration of the "A" score formula for the system under development in the same manner as the Quality score formula is considered.

so on. They are, rather, organized to correspond to the major pieces and major subpieces of things that are to be delivered, assembled and installed to make up the total operational system that is wanted. Whether this method of organizing a fabrication effort is good or bad is not at issue here. It is a fact that we organize major system fabrication efforts in this manner and that this method of organization has passed the test of practice well enough to have survived.

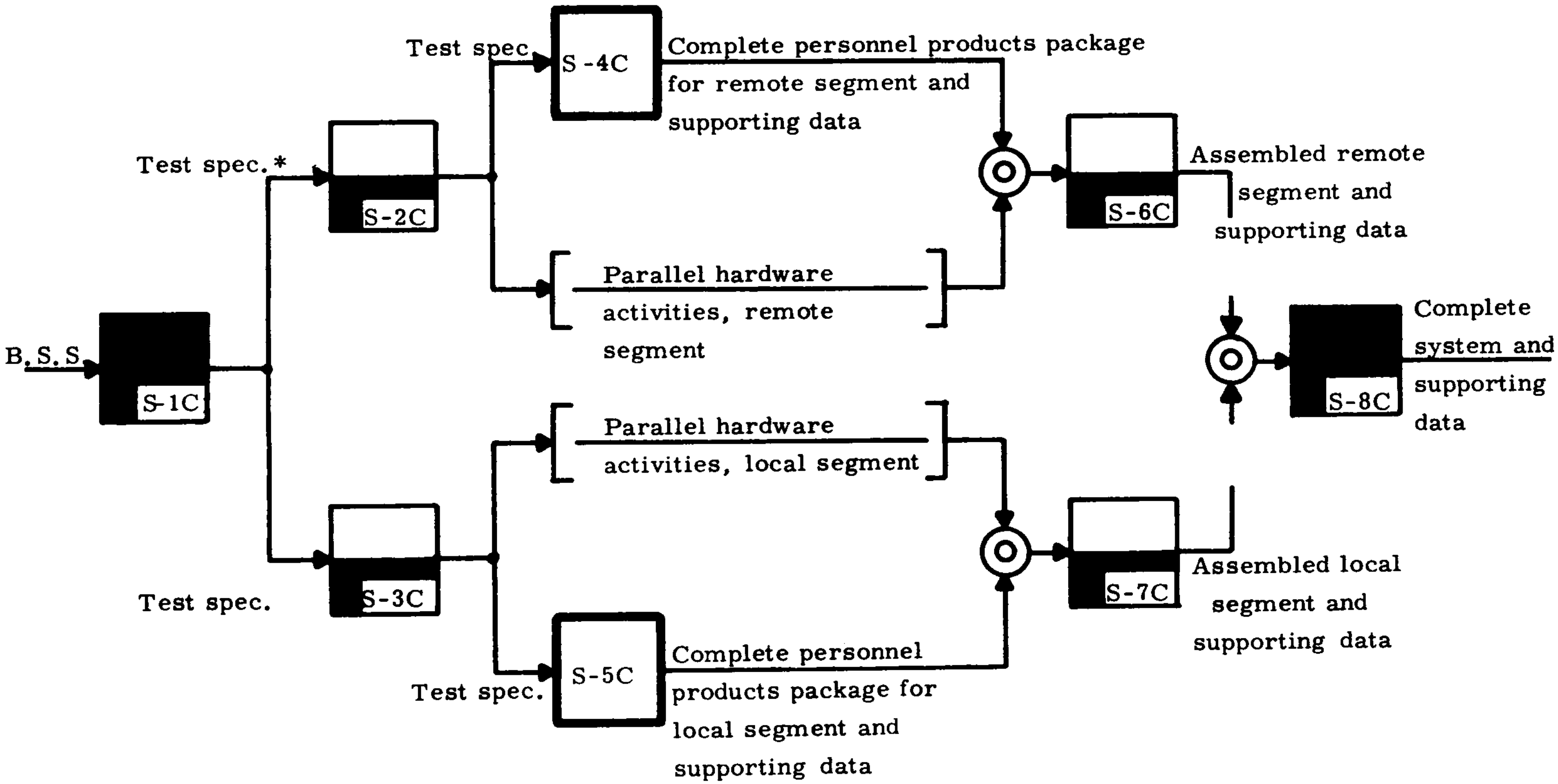
On the basis of practice,then, we first partition Function S into four component activities as shown in the following diagram.



In the diagram, Box S-1A and Box S-4A are at the "system" level. Boxes S-2A and S-3A are at the "segment" level, the remote and local segments being the first-order breakout of an aerospace system in terms of packages. Even at this first level of partitioning, the essential nature of the array that will be developed is revealed. The input to Box S-1A is the Basic System Specification. As an "order" for system design and fabrication, it is essentially a statement of how the output of Function S will be tested when it is delivered. The output of Box S-4A is the output of Function S. It includes the delivered, installed operational system and data to demonstrate that it passes the test implied by the input to S-1A. The test may be applied again by the customer, but presumably any testing the customer might do would develop data essentially the same as the data presented as supporting data in the output of Function S-4A..

In the partitioning of Function S, this test-product-plus-data pattern is preserved at the segment level. Thus, the input to Function S-2A, for example, is a description of the test of the remote segment which the output of the activity must pass, and the output is the delivered end product (the remote segment) plus data which show that its test has been passed. The pattern is repeated again for the local segment in Function S-3A. Function S-4A is then one which assembles and tests the remote and local segments as a complete operational system.

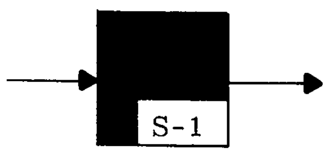
The pattern of specifying a test and applying the test to develop supporting data is repeated at all levels in the further partitioning of Function S. At the next level of partitioning, we call out the major packages within segments which are manufactured as packages. For example, typical packages within the local segment are structures, propulsion, guidance and control, and payload. Examples in the remote segment might be propellant handling and launch platform. In the model we are presenting here, we are not concerned primarily with the specific breakout of hardware packages, however; we are interested in typifying the hardware breakout in order to establish the level of breakout at which the personnel products package will appear in parallel. In our model we have placed the personnel products package in parallel with hardware package breakouts at the level implied above. Therefore, the next level of partitioning of Function S appears in the following diagram.



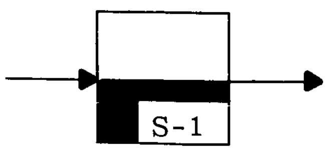
* The "package" covered by the test spec. may be determined by referring to S-6C.

In the array of activities shown, activities S-2B and S-3B develop descriptions of the tests by which the packages at the next level of breakdown will be evaluated. These tests are derived from the next higher level tests and become the "orders" for fabrication at the next lower level; thus they provide the basis for developing the supporting data which accompany each of the outputs at the next lower level.

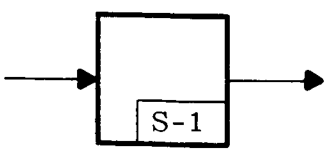
It can be seen that the personnel products package appears at the second level of breakdown. It can also be seen that a "clam-shell" type of pattern is emerging in which activities concerned at the system level run down the middle with segment-oriented activities on either side. This clam-shell pattern will be maintained with activities concerned with the remote segment on top and activities concerned with the local segment on the bottom. The boxes are coded to imply the level of breakout as follows:



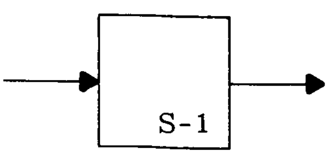
Activities concerned with dividing a system description to the segment level and with the integration of segments into a complete system.



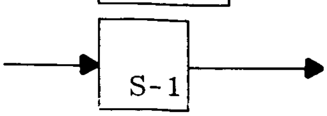
Activities concerned with dividing a segment into packages and with the integration of packages into segments (remote or local).



Activities concerned with dividing packages into first-order component packages and with integrating these into packages.

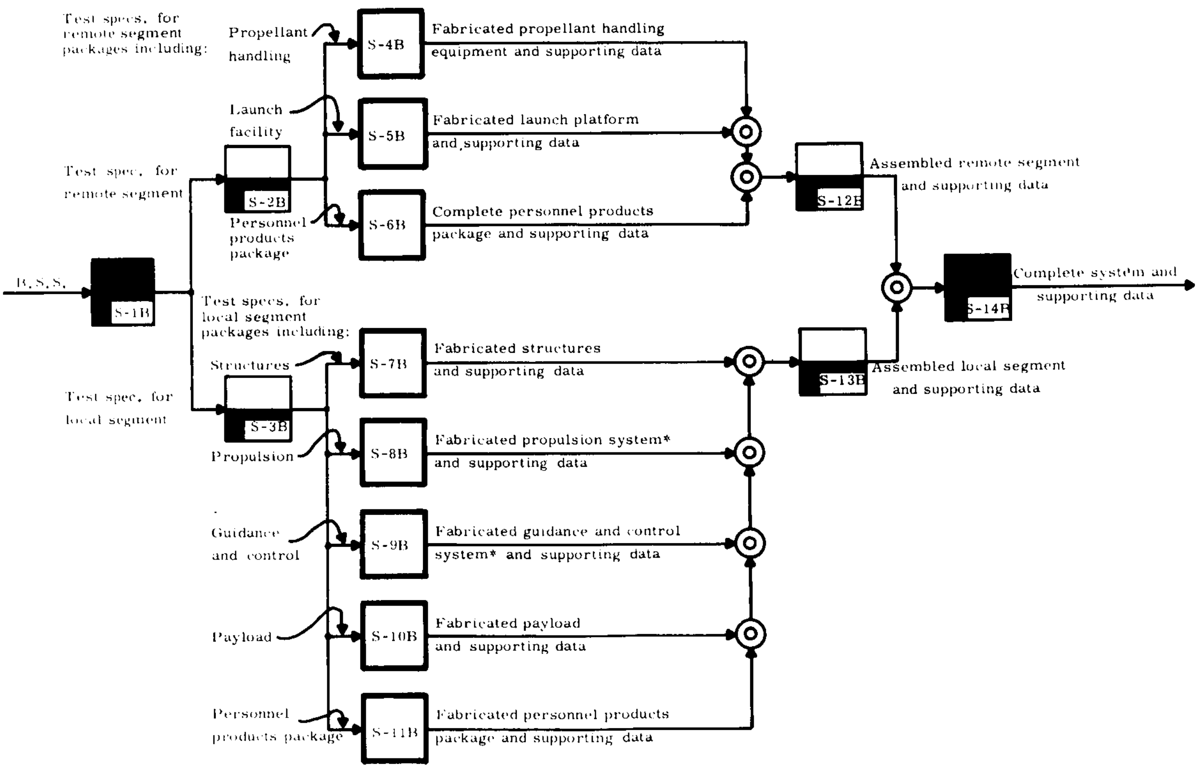


Activities concerned with dividing first-order component packages into second-order component packages and with integrating these.



Activities concerned with second-order component packages.

In presenting the model, the detail about hardware packages is not of use and therefore the detail will be reduced to a simple reminder, as shown in the following figure, which should be compared with the partitioning of Function S, shown above.



* more properly "package" than system

The form of the model for Function S, shown above, is the same as the form of the model for Functions D, E, F, and G. By comparing it with the previous partitioning of S, the reader will become familiar with the shorthand conventions employed to reduce unnecessary detail in the symbolic models.

As one moves from Function D to Function H in the full model the identification of the states changes; it is the overall pattern that remains the same. In the complete breakout of activities for each of these functions, the personnel products package activity is further broken down, sometimes to one lower level of detail, sometimes to two lower levels of detail.

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III. ACTIVITY RELATIONSHIP TO PERSONNEL PRODUCTS IN PHASE I OF DEVELOPMENT

The first three functions in the index model stand apart. These functions must be carried out without the benefit of a measure of goodness; they are themselves focused upon developing a measure of goodness which can be employed to monitor and control the development functions concerned with design and fabrication (Phases II and III). Thus, the objective of Functions A, B, and C is to produce a Basic System Specification which can then be used to guide the principal development cycle effort in Functions D through H. Not only are Functions A, B, and C unique because they must proceed without a measure of goodness; they are also unique in that typically they must be accomplished on a small budget. The budget for these functions will be small relative to the total development cycle budget simply because there is always the hazard that the outcome of Functions A, B, and C will be a recommendation not to proceed with system design and fabrication. Should this be the outcome, it would in most cases be quite unsatisfactory to find that major resources had been expended in the process of finding out that no system should be built.

In this chapter, we will consider the personnel products-related activities in Functions A, B, and C of the index model. (See also Report III.) None of the activities in the model is a pure personnel products-related activity; some of the activities involve almost no human factors or biotechnological participation. To partition these functions at a greater level of detail than that presented in the full model would not be likely to call out pure personnel-products activities unless a level of very fine detail were achieved. This is so because during this phase of a development cycle there must be a great deal of interaction among all of the areas of specialization involved. Task groups will be small because of the limited funds, and guidance for setting up highly specialized task groups will not be available because of the lack of criteria for establishing a highly structured process.

In view of the unique nature of the personnel products involvement in Functions A, B, and C, the component activities of these functions will be discussed here in running narrative form for the purpose of revealing the essential nature of the manner in which human factors and biotechnological skills will typically be employed. In reading what follows, it should be kept in mind that ordinarily it will not be known during this phase of the development process what role man will have in the operational system that will be developed. In fact, a major objective of this phase can be said to be the development of data that will provide a basis for determining whether or not man will have a role and to describe roughly what that role will be, if there is to be one.

We begin by considering Function A, which is composed of three component activities in the model. These activities are focused upon achieving cost and Quality score formulas for the system to be built. The development of a cost formula normally does not require human factors involvement. The development of the Quality score formula requires an investigation of the follow-on system rather than consideration of the operational system that is to be built. The preparation of the Quality score formula is therefore unlikely to require consideration of man in the system, for consideration of any system means should be excluded if possible. Human factors skills may be required if the follow-on system involves man performance, but any concern with such performance is not directed toward the development of personnel products as part of the operational system to be built. In sum, we can say that none of the component activities of Function A require personnel products-related activity in the strict sense in which we employ the concept of personnel products in these reports.

Function B in the index model can conveniently be considered in terms of two groups of component activities; the first group contains activity B-1 alone, the second group contains activities B-2, B-3, and B-4. Activity B-1 must produce all of the candidate system solutions and partial solutions that are to be considered in the course of the development cycle. For any aerospace system, it will be desirable (necessary) that candidate solutions be offered which must be implemented in part by human performance. The listing of candidate approaches involving human performance is clearly a personnel product-related activity. On the other hand, there is no reason to expect that such candidate solutions will be offered solely by human factors and biotechnology experts. What is required, is that the list of solutions offered include identification of functions and means relative to man in the system so there will be a good basis for testing to see whether or not man performance should be employed. An excellent basis for identifying likely solutions is the functional and means designs of similar systems already in operation or in later stages of development. It appears that activity B-1 can best be implemented by a group of experts in differing fields of engineering specialization who have broad familiarity with the state of the arts that are likely to be germane to the system problem they are studying.

Whereas activity B-1 must produce an extensive list of system candidates, and can in a sense be evaluated by counting the number of candidate solutions produced, activities B-2, B-3, and B-4 are concerned with getting rid of bad candidates, and may crudely be evaluated in terms of the number of bad solutions which they reject. Hypothesizing that certain candidate solutions relating to man in the system will be bad from the standpoint of cost or quality, or probability of success of development is clearly a personnel products-related activity. So is the process of demonstrating that the hypothesized bad solutions are indeed bad. Therefore, this group of activities clearly involves personnel products-related tasks. Yet, the specific work to be carried out cannot be predicted, for the successful conduct of these activities demands more of engineering ingenuity than it does of stylized procedure. It can reasonably be conjectured that human factors and biotechnological skills will be required to spot bad solutions and to demonstrate that they are indeed bad, but even the hypothesizing and testing probably could not be carried out successfully by a personnel products group in isolation. The development of hypotheses and procedures for testing will normally require the constant interaction of hardware engineering and man-related specialists to obtain an understanding of the criteria by which candidate solutions may be evaluated.

Function C in the index model is partitioned into ten component activities in the full model. Most of these involve personnel products-related tasks but none is strictly personnel products-oriented. Several of the activities demand the capability to estimate quality and cost consequences of choosing specified system solutions involving personnel products.

The objective of activity C-1 is to identify the most promising solution families among those candidate solutions which survive the filtering by activities B-2, B-3, and B-4. One way to approach this activity would be to generate alternate prime functional system designs and to employ these designs as the top-level family identifiers. Each prime system functional design would then be considered for the purpose of identifying all of the alternative means by which functions might be implemented. It would be desirable to identify all of those functions which could be allocated to man so that the effects of such allocations might be estimated. This would provide a basis for giving man-related solutions full opportunity to be represented. To achieve the objective of the activity, it would be necessary to estimate the effects of alternative man solutions upon total system quality and cost. Such estimates would have to take into account the limits of man capability and the secondary effects on quality and cost of including man in a system, such as the effects due to personnel support systems. It would also be necessary to predict rough "A" score formulas for systems involving man in order that unusually good or unusually bad "A" scores might be found. Thus, for example, a system which precluded the recovery of flight personnel in the case of certain system failures would probably be identified as one with an unusually bad "A" score. Costing estimates undertaken in this activity need be only so precise as to permit the ordering of system solutions with high confidence. What is desired is that it be possible to identify a subset of "likely-to-be-good" system solutions on the basis of gross estimation so that these may be examined later in more detail for the purpose of obtaining a reliable ordering of them. This second ordering of the best solution families is provided for by activities C-2, C-3, and C-4.

Activity C-2 is focused upon developing an approximate "A" score formula for each solution family identified in the output of activity C-1. The "A" score formula is to be used in activity C-4 as a basis for selecting the top solution families from the total list. Personnel products-related tasks must be carried out within activity C-2, when man in the system relates to an adjacent system and when the system affects man in its environment. Thus, for example, when the adjacent "system" of ethics demands that the lives of flight personnel be protected, there is a relationship between man in the system and an adjacent system that requires consideration in the "A" score formula. For a second example, when the system means under consideration releases toxic materials into the environment, there is a relationship which must also be reflected in the "A" score formula. In the case of both examples, personnel products would be demanded as elements of any system that might be built to provide for an acceptable "A" score. There is no comprehensive procedure for developing an "A" score formula. Examination of similar existing systems will often reveal important adjacent system relationships to be taken into account, however. It can be seen that personnel products-related tasks in this activity must be interwoven with hardware-related activities as in the case of other activities in this first phase of system development.

Activity C-3 calls for improved estimates of cost, quality, and Dev. Q characteristics of each solution family identified in the output of activity C-1. Inasmuch as every solution family will involve some personnel products, it will be necessary to determine the contribution of man-performance solutions to overall system cost and quality. In the case of each system, it will be necessary to estimate the range within which crew size might fall, and to provide parametric data with respect to the weight, power, and volume effects of crews of varying sizes.

The data provided by activities C-2 and C-3 provide the basis in activity C-4 for identifying a few top solution families. These will be the families with the best cost, quality attributes as families. Human factors and biotechnological personnel may be desirable members of the team which selects the top solution families, but there is nothing that is inherently personnel product-oriented in the process of making the selections.

Activities C-5 and C-6 form a question-and-answer pair. In activity C-5, each top solution family is considered for the purpose of developing questions (or hypotheses) about the characteristics of family members in terms of cost and quality, given various subfamily approaches to implementation. Activity C-5 thus sets the stage for extensive system analyses in activity C-6. Clearly, in activity C-5, it will be necessary to formulate questions about alternative man-performance solutions within each solution family. However, such questions will not be independent of other system attributes to be investigated, and therefore the called-for man-related investigations cannot be formulated independently. What is desired is that the set of questions formulated be so comprehensive that they will generate the data necessary to identify an acceptable system solution within each of the solution families considered. If questions about solutions involving personnel products are not raised at this time, most likely it will be difficult to introduce such solutions later in the development process.

Activity C-6 is essentially a system analytic effort. It is focused upon obtaining answers to the questions posed in activity C-5. Inasmuch as many of the questions will require that the cost and quality effects of personnel products solutions be investigated, activity C-6 must involve extensive personnel products study. The study that is required will focus upon determining limits of personnel product solutions, and upon determining quantitatively how various personnel product solutions will directly and indirectly affect overall system quality and cost. To enable trade-offs to be made, the data will ordinarily be generated in parametric form, considering crew sizes over possible ranges, for example.

As in the case of activity C-4, activity C-7 does not require constructive personnel products efforts. Activity C-7 is directed toward the identification of a typical acceptable system solution from within each solution family considered in activities C-5 and C-6. The basis for selection is provided in the data output of activity C-6. It is not the purpose of activity C-7 to identify a system solution that will be employed in the design and fabrication phases that are to follow. Rather, the typical system solutions identified in activity C-7 provide a basis for obtaining the detailed information necessary to develop a Basic System Specification as an output of Function C.

For each system solution identified in activity C-7, a typical development cycle plan is prepared in activity C-8. The purpose in preparing the development cycle plan is to provide one of the bases necessary to enable a good estimate of cost to be made for each system solution. The personnel products involvement in this activity is not in doubt. One important guideline for preparing the needed development cycle plan is the development cycle model presented in Report I and the information contained in this report. The personnel product-related involvement will therefore be concerned with identifying the personnel product-related activities that must be carried out within each development cycle. It will be necessary for this aspect of development cycle planning to be carried out in close concert with hardware planning, and, for this reason, human factors and biotechnological involvement should not be called out as an entirely separate activity.

In activity C-9, refined cost, quality, and Dev. Q estimates must be provided for each typical system solution considered in activity C-8. Again, the cost and quality effects of proposed personnel product solutions must be estimated, requiring the participation of human factors and biotechnological specialists. But here the objective is not to determine the optimal use of personnel products. Rather, it is to establish a basis in terms of cost and quality for the preparation of a specification of the system to be designed in Function D.

Data will be provided in the output of activity C-9 for each top solution studied in the sequence of activities C-5 through C-9. These data will provide a basis for preparing a recommendation to the customer for proceeding (or not proceeding) with design and fabrication of a physical system. If the customer's concurrence is obtained in activity C-10, then a Basic System Specification must be prepared incorporating quality, cost, "A" score, and Dev. Q information about the system that is desired. Consideration of personnel products will enter into the preparation of this Basic System Specification only if there are constraints to be placed upon the system to be designed which affect personnel products.

IV. DETERMINATION OF PRIME SYSTEM FUNCTIONS TO BE PERFORMED BY MAN (OPERATOR PERFORMANCE)

Activity Group Requirements and General Considerations

The strategy underlying the development cycle model dictates that Function D focus upon the identification of a functional design for the prime system; thus the output of Function D is a stabilized functional design. Stabilization implies that the prime system design will not be changed as the development cycle proceeds through the rest of the design effort and through fabrication. To have confidence at the completion of Function D that it will be possible to complete design and fabrication according to the stabilized functional design of the prime system, there must be data to show that there is at least one satisfactory system solution which can be implemented. This means that within Function D there must be a thorough investigation of the manner in which the remainder of the development cycle can be carried out for each alternative functional design that is seriously considered.

A functional design does not indicate a means by which the functions will be implemented. Therefore, in a pure functional design there will be no indication of which functions may be implemented by human performance. However, to demonstrate that the recommended functional design is feasible to implement, there must be presented in the accompanying supporting data package a thorough study of the functions which might be implemented by human performance with indication of those which should be carried out by man. Even in the case of a system which ultimately will be unmanned, such data will be necessary to provide for confidence in the decision to stabilize a specific prime functional design.

In the case of the remote segment, it will be sufficient, for the purposes of prosecuting an effective development cycle, for the output of Function D to provide only supporting data with respect to the possible role of man in a system which might be developed on the basis of the recommended prime functional design. In the case of the local segment, such data will not be sufficient; a recommended crew size must also be given. The underlying rationale is as follows. Function E, which follows immediately, calls for the identification of prime system means; in the local segment it will therefore be necessary in Function E to identify the propulsion means to be employed in the operational system. To identify propulsion means, the size of the crew for the local segment must be known if an optimal system is to be developed, for generally there will be an increasing relation between crew size and the capability required of the propulsion package. Optimization of system quality and cost is at stake because of the potential significant effect of human performance both upon quality and upon cost, and, of course, as performance demands increase, so must the size of the crew. Therefore, to be prepared for the propulsion means decision in Function E, it is necessary for the output of Function D to include a decision with respect to the size of the crew for the local segment.

Because of the need for determining crew size as a basis for initiating Function E, the personnel products-related activity in Function D that is concerned with local segment design (activity D-7) must include determination of which functions in the prime system design will be allocated for implementation by crew members in the local segment. This amounts to a means allocation to prime functions ahead of schedule, for it is in Function E that such means allocations are called for. With this exception, however, the personnel products-related activities in Function D will be carried out in concert with parallel hardware-related activities for the purpose of achieving a joint determination of a recommended prime functional design. The requirement for the prime functional design to be stabilized first is bound up in the overall strategy of the development cycle. That strategy holds that functional design must precede means design, and that prime system design must precede design of the additive set.

Relationship of the Group to the Development Cycle Model

This activity group includes two activities in the model, activity D-4 and activity D-7. The output of activity D-4 identifies the operator performance allocations to be made in the remote segment for each of several possible crew sizes. These data are provided to support the overall objective of Function D, which is to identify and stabilize a functional design of the prime system. Activity D-7 performs an analogous role with respect to the local segment. The output of activity D-7, however, also includes identification of a recommended crew size for the local segment. In general, activities D-4 and D-7 differ also in that design considerations for the local segment are limited by weight, power, and volume budgets, whereas design for the remote segment is not. Activities D-4 and D-7 are carried out in parallel with a number of similar activities concerned with developing the relationship of the prime functional design to the hardware packages in the system. Inasmuch as the objective is to produce one prime functional design, constant cooperation and interaction between remote and local design efforts, and between man-oriented and hardware-oriented efforts is required throughout Function D. Thus, although D-4 and D-7 are shown in the model in simple parallel with each other and with hardware activities, there must be in fact a constant flow of information among all of the parallel activities.

If we assume that the personnel employed in the prosecution of Functions A, B, and C are not the same as those who initiate and carry out Phases II and III of the development cycle, then activities D-4 and D-7 have no important antecedents. The nature of the work that is carried out in these activities is similar to the human factors efforts required in Function C, but in Function D the design effort is guided and bounded by a Basic System Specification, which provides a criterion against which to judge the outputs produced.

Although D-4 and D-7 may have no antecedent, virtually every personnel product-related activity in the development cycle is in some sense a descendant of D-4 or of D-7. To provide the data necessary for confidence in the selection of a prime functional design, data which demonstrate that there is a complete system solution associated with the recommended prime functional design are required in Function D. To generate these data, activities D-4 and D-7 must thoroughly explore all of the man-related activities that must follow in the development cycle. To explore and predict the feasibility of carrying out each of these man-related activities, D-4 and D-7 must employ the special areas within human factors technology and biotechnology associated with each. As a result of these exercises, D-4 and D-7 quite naturally become the wellspring from which the subsequent personnel product-related activities will issue.

The specific activity group that is most closely related to D-4 and D-7 is the group of activities concerned with the technical management of personnel products development (see Chapter V). To carry out the required technical management, this activity group requires the data and experience of activities D-4 and D-7 as a platform for an overview of personnel products development and the relationship of personnel products to the total system effort.

Resources Needed

If activities D-4 and D-7 are seen as the precursors of the activity group that is concerned with technical management of personnel products development, then the personnel resources required to implement D-4 and D-7 will be seen to be compatible with the personnel resources required to implement the following technical management activities. It is probably important to see this relationship because it lends extra justification to the demands which should be met for highly trained senior human factors and biotechnological personnel to implement D-4 and D-7. Implementation of these activities will require a thorough consideration of all of the activities in the model that are related to personnel products in Functions E, F, G, and H. These activities cover the gamut of specialization within human factors and biotechnology. To predict the manner in which these activities may be carried out such that they will take full advantage of the best state of the art requires personnel with broad technical training and with previous experience in implementing the kinds of activities they are trying to predict. It also requires personnel with management skill to preclude the planning of activities which are simply not manageable.

Yet another reason for requiring broadly trained, experienced personnel derives from the fact that there must be continuous interaction among all of the specialists involved in Function D thus suggesting that it will be advantageous to employ as small a group as possible. To have a small, effective group requires that the members of the group all have a diversity of skills at a relatively high level.

There is nothing inherent in the nature of the work involved in Function D which requires resources other than highly skilled personnel with "pencils and paper." However, from time to time, it may be necessary to resort to mock-ups and even to applied experimentation in order to develop data necessary to support a recommendation with respect to the allocation of performance to man. The requirement in this regard is most stringent with respect to activity D-7 for the size of the crew in the local segment must be stabilized in the output state of Function D. The data gathered with respect to the remote segment do not have to support a final recommendation with respect to the allocation of functions to operators.

Recommendation of Operator Performance Allocations and Crew Size Activity D-4 (Remote)

The output of this activity includes the functions recommended for implementation by the remote segment crew members. Specific attention is directed toward those functions in the prime system design that are to be allocated for implementation by operator performances. Supporting data justifying these recommendations must be included for these data must provide a basis for the functional design of the prime system to be stabilized in the output of Function D. Therefore, consideration should be given to the allocations that would be made for differing crew sizes. The functional design which is employed as the basis for the recommendations must be the same functional design that is employed as the basis of hardware recommendations. Whereas it is necessary that crew size for the <u>local</u> segment be stabilized in the output of Function D, it is not necessary that data be provided to stabilize the crew size for the remote segment. What is required is that sufficient data be provided to enable stabilization of a complete prime functional design with confidence that the stabilization will not result in personnel products problems later in the development cycle as a consequence of the limitation placed upon design by stabilization.

The key input to activity D-4 derives from D-2; like the input to activity D-7, it is based upon analyses of the system as a whole and of the remote segment in particular. Unlike the input to activity D-7, it does not contain weight, power, and volume budgets. It does contain a reliability budget, and identification of the manner in which the output of activity D-4 will be evaluated.

Activity D-7 (Local)

The key output of this activity is a documented recommendation of the local functions in the prime functional design of the system that should be assigned for implementation by human performance. Recommendations should be provided for each of several different crew sizes so that crew size may be chosen without redetermining operator performance allocations iteratively. Thus, the crew sizes considered should include every crew size that is a likely candidate for adoption, but one crew size should be recommended. Supporting data should be provided for the recommendation of crew size and for the allocation of operator performances for each of the various crew sizes considered. The functions allocated for operator performance should be functions in the prime functional design that is recommended. If variations in the prime functional design are presented for consideration, then recommended operator performance allocations for each variation should be provided.

The supporting data provided should include data which demonstrate that selection of the recommended prime functional design and that acceptance of the recommended operator performance allocations will not preclude the completion of the design and fabrication effort with delivery of an operational system of the desired cost and quality. Thus, data must be presented to show that there is at least one acceptable <u>complete</u> system solution within the boundaries established by the recommendation (from the standpoint of personnel products development).

The key input to D-7 is a requirement statement which derives from activity D-3. Activity D-3 will have been carried out for the purpose of identifying the major physical packages which will make up the system that is to be developed. These physical packages will have been generated on the basis of an exploration of alternative functional designs and will relate to a specific functional design family. The requirement which is the input to D-7 will identify the major physical packages and the categories of functions to be implemented by each. It will also present tentative weight, power, volume, and reliability budgets, and will set forth the criteria by which the output of activity D-7 will be evaluated.

Discussion

Of the two activities in this group, D-4 is, in one sense at least, the simpler one. Thus, D-4 does not have to be carried out under constraints of weight, power, and volume, as does D-7. We will begin by discussing D-4 and then extend our concern to the special aspects of D-4, which derives from the fact that there is a basic weight constraint to be considered.

There are two basic ways in which D-4 may be related to the parallel efforts in Function D that are concerned with hardware packages. One approach to D-4 might be to permit the hardware-oriented activities jointly to generate alternative functional designs of the prime system, and then to employ D-4 for the purpose of identifying those functions in each prime functional design that might be implemented by means of operator performance. A different approach would be to engage activity D-4 in the initial development of the alternative functional designs in concert with the hardware-related activities. The latter approach might be expected to produce functional designs that take advantage of the capabilities of man in more ways than functional designs produced without the active participation of activity D-4. And, in general, it might be argued that it is desirable to consider a broad spectrum of types of system solutions. One may, however, argue well for the former approach. In most aerospace systems, hardware packages may be associated in a more or less meaningful way with a collection of related functions, so that the underlying functional basis for each hardware package may be comprehended.

Indeed, many hardware packages are named for the class of function which they implement; for example, propulsion system, guidance system, and so on. The performances which are eventually allocated to crew members, however, seldom form a coherent group in this manner. They tend to be performances from here and there throughout the overall functional flow of the system. They are the ones for which man is the means of choice. The fact that man is typically employed in this manner makes it difficult to place a specific requirement on activity D-4, and makes it difficult to conceive of a set of system functions that might be identified as of primary concern to activity D-4.

Without intending to imply that it is a superior approach, but merely to simplify the discussion, we will assume that activity D-4 is initiated in parallel with the hardware-oriented functions at the package level, and that the process of generating alternative functional designs is an interactive one among all activities in parallel.

In theory, Function D might be initiated by a Basic System Specification which does not identify a preferred type of system solution. Such a Basic System Specification would give designers in Function D maximum freedom to explore alternatives and to pick the system solution family and the stabilized prime system design with the highest desirability. In fact, by the time a real development cycle enters Function D, the solution approach of choice has been identified and work in Function D will focus upon an exploration of alternative members of the family for the purpose of identifying a preferred subfamily defined by a given overall prime functional design. If a preferred system solution family is identified in the Basic System Specification, then there must have been exploration of that family in Function C, and there must be existing data which identify various subfamilies, and which identify the penalties and benefits associated with each. Such data will provide a basis for an immediate entry into the process of generating the required functional design in Function D. It can therefore be expected that activity D-4 and the associated hardware-related activities for the remote segment will begin an immediate interactive process with each other and with the parallel activities concerned with the local segment.

The functional design of the desired system will not identify the packaging of means, and, therefore, there will not be component arrays of functions within it which neatly fit into one segment or the other, or which neatly fit into one "subsystem" package or the other. The packaging will be made up after the fact in the manner which best achieves overall development cycle goals. Therefore, the initial consideration of the functional design of the system will not be a process in which subtasks can be cleanly called out and allocated to activities. Rather, initially, the lines of demarcation between activities may have to be ignored to a large extent until acceptable overall functional designs have been elaborated to an extent which permits identifying the likely ways in which subsystem packages will be configured. Activity D-4 may therefore start out without a clean demarcation of its proper concern and may gradually work toward an achievement of that demarcation.

The alternative functional designs considered in Function D will not and cannot be developed in a medium that is void of means considerations. In the case of an aerospace system, the hardware means will be at the heart of the matter of design, and human performance will be employed when it is justifiable to complete the set of means necessary to implement a functional design. This fact establishes a "follower" position for activity D-4 different from the role of a similar activity in a development cycle for a system in which man is the central means; for example, a decision-making system. As alternative functional designs within the family of choice are developed, and as possible hardware implementation is identified, it will be the role of activity D-4 to review these, to correct and extend them where there is a need to do so, and to identify the functions which might be implemented by man in each. The principal concern must be with the identification of operator performance. Then, by considering the implications of various combinations of allocations, the most defensible allocation must be identified for each prime functional design under consideration. Ideally, optimal solutions from the standpoint of activity D-5 will not be sought, but rather consideration will be given to alternatives along meaningful continua so that trade-offs can be made when all of the studies of implications by hardware package groups are brought together with data developed with respect to personnel products. Even when the number of alternative prime functional designs has dwindled as the result of comparisons, it will be desirable to continue the process of identifying alternatives and presenting study data parametrically. In the terminal phases of activity D-4, it will be necessary to generate supporting data to show that if the recommended functional design is accepted and stabilized, that it will be possible to complete those parts of design and fabrication concerned with personnel products development, such that the resulting system will fall in the neighborhood of the target cost and quality. Thus, it must be shown that there is at least one approach to personnel products development within the recommended prime functional design that will not give rise to system cost and quality problems because of personnel products problems.

It is not required that the output of D-4 or D-7 provide a basis for stabilizing the allocation of operator performances in Function D. The firm allocation of operator performances is a means allocation which should be carried out in Function E.

Whereas variations in crew size are considered in activity D-4 for the purpose of permitting trade-offs to be made in achieving a stabilized prime functional design, in activity D-7 crew size is considered as a major topic of concern in its own right. The output state of Function D must include a stabilized crew size for the local segment to enable Human Support System design to get under way immediately, to provide a basis for weight, power, and volume budgets, and a basis for the stabilization of the means design for the prime system, all in Function E. Therefore, activity D-7 will differ from activity D-4 in that specific study will have to be devoted to the implications of employing crews of different sizes with respect to overall system cost and quality. The input to D-7 will provide guidance with respect to weight, power, volume, and reliability budgets, and study must be undertaken in D-7 to assist in the development of data to support firm recommendations with respect to these budgets in the output of activity D-9, which follows D-7 at the segment level. To determine the implications of different crew sizes, it will be necessary to investigate thoroughly and to predict requirements for the crew to carry out maintenance activities, to operate the Human Support System, and so on. It will be necessary also to determine the weight, power, and volume that will be absorbed by the Human Support System needed for each crew size.

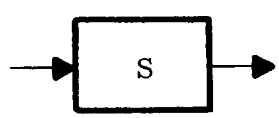
The decisions made on the basis of the data generated by activities D-4 and D-7 will stabilize the prime functional design of the system and the crew size for the local segment. Once this stabilization has been accomplished, a major design freedom will have been taken away, and all future design activities related to personnel products will be constrained within the stabilized functional design and crew size. If activities D-4 and D-7 were not carried out in Function D, it is unlikely that the stabilized function design achieved in the output of Function D would permit an optimal system solution to be developed. The effect of attempting to "patch in" activities D-4 and D-7 at some later time would be roughly equivalent to an attempt to patch in consideration of a major hardware package, such as the propulsion system, at some later point in the development cycle if propulsion means were not considered at all in the selection of the prime functional design.

V. TECHNICAL MANAGEMENT OF PERSONNEL PRODUCTS DEVELOPMENT

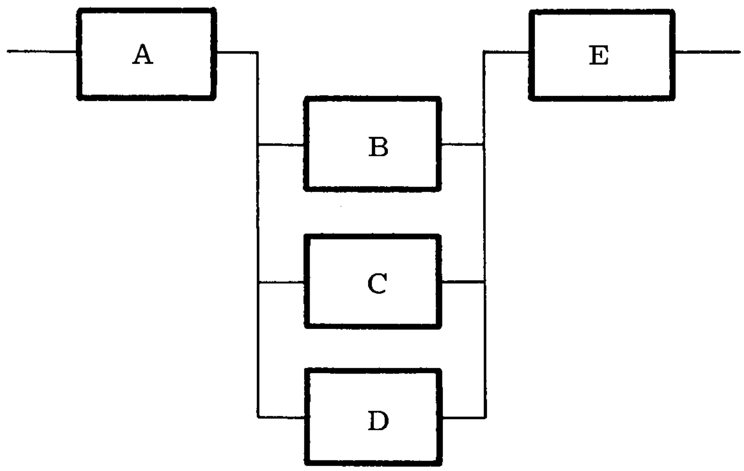
Activity Group Requirements and General Considerations

Products generated in a development cycle that are related to personnel include analyses, manuals, equipment, personnel selection tests, training materials, and human engineering designs. Thus, these products are interim and final products of the activities in a development cycle that are related to putting man into an operational system in an optimal way. The concern of the activity group discussed here is to ensure that all of these interim and final products meet allocated requirements so that the Cost and Quality targets for the operational system are achieved. The activities in this group are concerned, therefore, not with the technical preparation of these products per se, but rather with the specification of what the products must be, and with the test or demonstration of the fact that the products meet specification.

The basic requirement for the personnel products package activity group derives from the complexity and number of personnel products required to package man and his necessary accoutrements for a system. In developing <u>personnel end products</u> for a very simple piece of equipment, the total activity could be shown as follows:



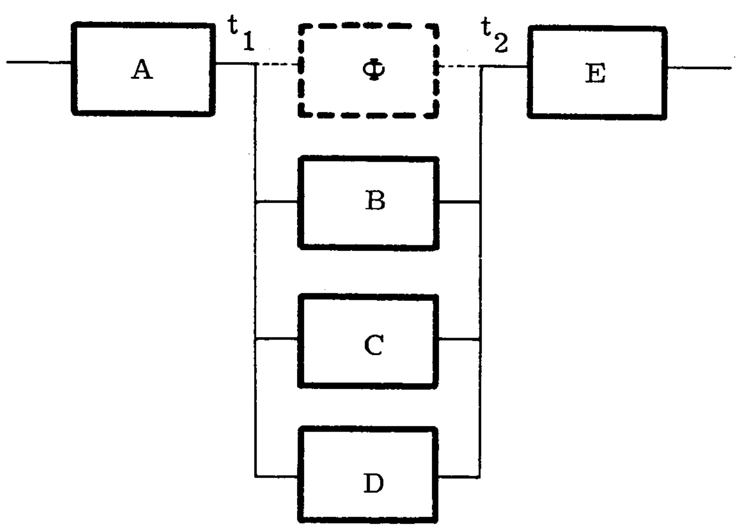
This single box would include determining what is required to meet the performance specification, accomplishing the work, testing the results, and delivering the end product and test data. In the development of simple portable weapons, for example, the only personnel product usually of concern is the human engineering of the weapon for use by combat personnel; other aspects of personnel products packaging are either not relevant to the problem, or are associated with adjacent systems. In this case, a one-box description might do. In aerospace systems, however, personnel products and interim related products consist of many subsets of products for which requirements or specifications must be established, and for which integrated test and evaluation programs must be developed. This increase in complexity creates the need for a special group of activities in the development process that are devoted exclusively to the problems of allocation and enforcement of requirements, and to the problem of integrating outputs produced in answer to requirements. A diagram showing the typical relationship of activities organized for this purpose is shown below:



In this diagram, Block A represents the activity of specifying requirements for the production of personnel products (or possibly of personnel products designs) in Blocks B, C, and D. This group of three blocks in parallel represents the activities which produce products and test data to show that they meet the specifications. Ideally, the specifications will be given in terms of the criteria and methods by which the end products of Blocks B, C, and D will be tested. Block E represents the activity of providing for the integration of these end products to meet the specification which was the initiating input to Block A.

The general model shown above could be applied equally well to the development of hardware, in which case the Blocks B, C, and D would represent the production of hardware packages. The analogy with the hardware situation is apt, since in the area of personnel products development there is growth in specialization similar to that experienced in hardware development. This growing specialization generates an additional requirement for imposing an activity responsible for technical management on the personnel products development activities.

If effective technical control of the personnel products activities is to be exercised, there must be a continuity of effort on the part of the personnel products activities. The above simplified model shows one activity (A) as simply providing inputs to B, C, and D, and then shows a second activity (E) as the picture at a later point in time to test the products of these activities. To provide effective integration of the activities in the various blocks, and to ensure compliance with schedules and cost, an additional function must be added to the above model. For purposes of the development cycle model, this additional function is identified as a phi function. The relationship of the phi function is shown in the following diagram:



In effect, the phi function in the above model maintains continuity of technical control between time t_1 and time t_2.

In the full development cycle model, there are many arrays of activities which match the model given above in terms of activities A, B, C, D, and

E. In each of these arrays, the activities which correspond to A and E in this model are concerned with the technical management of other activities which produce personnel products or personnel products designs (represented by B, C, D). In this chapter, it will be our objective to identify all of these activities in the model that are concerned with the technical management of personnel products activities. It will also be our objective to identify how these technical management activities relate to all of the other activities in the development cycle. In this discussion, we will include the concept of the _phi_ function, which is a necessary function in the real world of technical management as opposed to the somewhat ideal world described by the "GO" model. The technical management activities are required to ensure that the personnel products development activities in a real-world development cycle do not stray so far out of bounds that the cost and quality of the delivered end product will be compromised.

Relationship of the Group to the Development Cycle Model

On each of the last four pages of the development cycle model, the personnel products package activity group provides the starting point and terminal point of work on personnel products. The techniques and approaches used in the remote segment are so similar to those used in the local segment that the emphasis in this and later sections of this chapter will be focused almost exclusively on the local segment. We assume the reader will regard what is said about the local segment as applicable to the remote segment except as noted.

Specific activities within the _local_ segment of the personnel products package activity group include the pairs: (E-4 and E-14) (F-4 and F-12) (G-4 and G-20) (H-4 and H-16). The corresponding pairs in the line of development of the remote segment are: (E-3 and E-13) (F-3 and F-11) (G-3 and G-19) (H-3 and H-15). Formal consideration of the personnel products package (in the local segment) begins in Function E with activity E-4. However, many of the activities that have preceded this point in the development cycle are directly relevant to the activities of personnel products packaging. Assuming that consideration will be given to all that has preceded personnel products packaging, several of these activities are worthy of special note. Early in the development cycle model (activity A-2), the Q scoring formula is stabilized. The parameters of this formula and their derivatives are especially critical to the packaging activity. Once this formula is established, the packaging activity is limited in the types of products that can and should be produced, and in the types of measures that can be applied to these products. Criteria for quality, other than Q, can be used in a specification for a specific personnel product activity only if they are derivable from the basic elements of the Q scoring formula. This eliminates from consideration such criteria as "good human engineering practice," and establishes the basic structure for the packaging activity.

A second major activity with implications for personnel products packaging is activity C-6 which provides data regarding the cost, quality and probability of development success of man-related solutions to the system problem. This activity provides the first "hard" data regarding the relationship between man's performance capabilities, C, Q, and Dev. Q. Although these data will be improved in later activities, this initial cut is critical in that it uncovers limitations on solutions that might be available for use in the packaging activity. For example, data resulting from this activity might indicate that training alone would not be an effective approach for attaining the requisite human performance capabilities required for the system.

A third major source of impact and data for the personnel products packaging activity is the Basic System Specification which is provided as an input to activity D-1. This specification summarizes the findings of the preceding functions (Functions A, B, and C) and may further limit the solutions available by providing "customer accepted" data regarding human performance capabilities.

The fourth activity which has considerable impact on the packaging activity is activity D-7 which results in recommended operator performance allocations and crew size. This activity provides not merely the recommended solution to the "crew-role" problem but also the supporting data on which the recommendation is based. These supportive data provide the major input to the packaging activity since they will include not only the available solutions within the selected approach, but also the probability estimates of success for each candidate, and the preliminary cost estimates. The initial processing in the packaging activity will consist in a further definition and refinement of these data in greater detail and depth.

The eight activities contained within the personnel products packaging activity for the local segment can be treated, for discussion purposes, as consisting of four pairs (e.g., E-4 and E-14) which bound personnel products activities for a given function. The first activity in each of these pairs provides the specification of requirements allocations to be met by the various personnel products. The second member of the activity pair provides the application of the verification and integration processes to the actual outputs of the personnel products activities.

As the development cycle moves through the functions, the degree of detail with which allocations can be made in the packaging activity increases as the freedom for selecting alternative approaches and allocations decreases. A significant change in the nature of the packaging activity pairs occurs in Function G. Prior to this point, the packaging activity provides direct input of specifications into the various technically-oriented personnel product activities. For example, in Function E, activity E-4 provides input directly to activities E-9, E-10, E-11, and E-12 which cover recommendations for maintenance functions, maintenance of operator performance, human engineering of operator interfaces, and functional and means design of the human support system. When we reach Function G, however, the packaging activity provides specification not to individual personnel products activities but to two major groups of activities: those directly concerned with achieving human performance capabilities, and the Human Support System. Although these two major groups may proceed independently at this stage of development, they must nevertheless respond properly to each others needs. To ensure that they <u>do</u> respond properly, the packaging activity assumes a technical monitoring role over them, and relegates the technical control of the <u>individual</u> personnel products activities to a new pair of monitoring activities, activities G-6 and G-18 (in the local segment). (See Chapter XI.)

The final outputs of the packaging activity group occur at activity H-16 with the integration of the complete personnel products package which includes a verified set of personnel, materials for maintaining their performance, and a Human Support System to protect this performance capability from environmental degradation. These products have been tested as an integral unit and are ready for insertion into the operational system.

Resources Needed

To ensure adequate staffing of the personnel products packaging activity, either of two approaches may be utilized. The first approach would be to initiate manning of this activity prior to the actual time the activity would be performed. The initial skeleton group would accomplish preliminary planning and would develop the necessary analytical tools for accomplishing the activity. The second approach would be to utilize personnel already involved in the system development cycle for staffing the packaging activity group. It would follow from the discussion of the relationship of this activity group to preceding activities that the likely candidates would be some of those personnel responsible for activities A-2, C-7, and D-7, all of which are essentially precursors of the packaging activity. This second approach would have the advantage of utilizing the experience gained in the preliminary activities throughout the development cycle and would thus provide continuity in the implementation of the development cycle model. Regardless of the approach taken, the manning requirements will increase in this activity as progress is made through the development cycle, at least until Function G when the crew package technical management group may drain off personnel and responsibilities. This increase in manning requirements is due to the increasing detail that will be encountered in the later activities of this group and to the increasing complexity of testing and verification that will be required for the later interim and final personnel products.

The requirements for personnel assigned to this activity group are best summarized by the term "diversity." Whereas an activity such as E-11, dealing with the "human engineering" of operator interfaces, required primarily practitioners of the specific discipline of human engineering, the packaging activity requires a multidisciplinary approach. This is necessitated by the fact that this activity is preparing allocations and specifications for all of the other personnel products activities. If these specifications are to be practical and meaningful to the quality elements of the system, they must be prepared by personnel who are familiar with the disciplines involved on the personnel products side, and with the system concept and quality formulations on the systems side. Personnel who have been cross-trained in several relevant disciplines would be ideal for this assignment. A secondary characterization of the personnel required for staffing this activity group would be the word "senior." While it is true that every organization expresses a need for senior personnel, it is critical that this activity be staffed with a higher percentage of senior personnel than other personnel products activities. The reason for this derives from the nature of the activities required of the group. The specification of requirements for personnel products is essentially a supervisory or technical management function. Further, the implementation of the phi functions means that personnel in this activity will have to serve as technical monitors, trade-off and interface arbiters, and, finally, as decision-makers.

The amount and type of equipment required for implementing the activity depends on the complexity of the system and the specific techniques needed for verification and testing of personnel products. Such verification may require equipment ranging from simple cardboard mock-ups to complex operational and environmental simulators. The actual fabrication and operation of these devices may not actually be the responsibility of the personnel products packaging activity, but the requirements for the equipment must be delineated and defined by this group, as well as the requirements for operating and test procedures.

In addition to direct equipment requirements such as simulators, this activity will normally require data-processing equipment support. The data-processing equipment and attendant support personnel need not actually "belong" to the packaging group, as long as they are responsive to the needs of this group for a complete, usable, up-to-date data pool covering all aspects of personnel products development for aerospace systems.

Special Note

This group of activities does not lend itself readily to the format of the chapters concerned with design and fabrication activities. The primary problem of exposition is that the activity pairs have much in common; all implement a common technical management strategy. For this reason, the discussion which follows will treat the management pairs in a modified format. Activities E-4 and E-14 will be discussed in greatest detail; the other members of the group will be discussed in terms of their unique attributes only.

Contributions to Functional Design of the Additive Set and Selection of Personnel Products in the Prime System
Activity E-4 (Local)

Outputs

The primary outputs of this activity are the requirements and specifications for the following personnel products: recommended maintenance functions, recommended maintenance of operator performance, articulation of operator interfaces, and functional design of the Human Support System (E-9, E-10, E-11, E-12). The specifications will allocate a tentative cost and time budget to each of these activities. The specifications will also indicate what tests and demonstrations will be used to determine whether or not the outputs of E-9, E-10, E-11, and E-12 are good.

The outputs (specifications) of this activity should be sufficiently detailed for the follow-on activities to clearly understand what they must produce and how the "goodness" of the product will be tested.

In addition to specification of the final testing to be applied to the personnel products, the output of this activity should specify the techniques to be employed in interim testing by the phi function. Interim monitoring is required to ensure that no time loss is incurred in meeting schedules due to retrofit activities required as a result of unacceptable personnel product outputs.

The outputs associated with the remote segment (E-3) will be of the same type as for the local segment (E-4). The only difference is that certain quality-related elements, such as weight and volume, may not be as critical for the remote segment as for the local segment.

Requirements

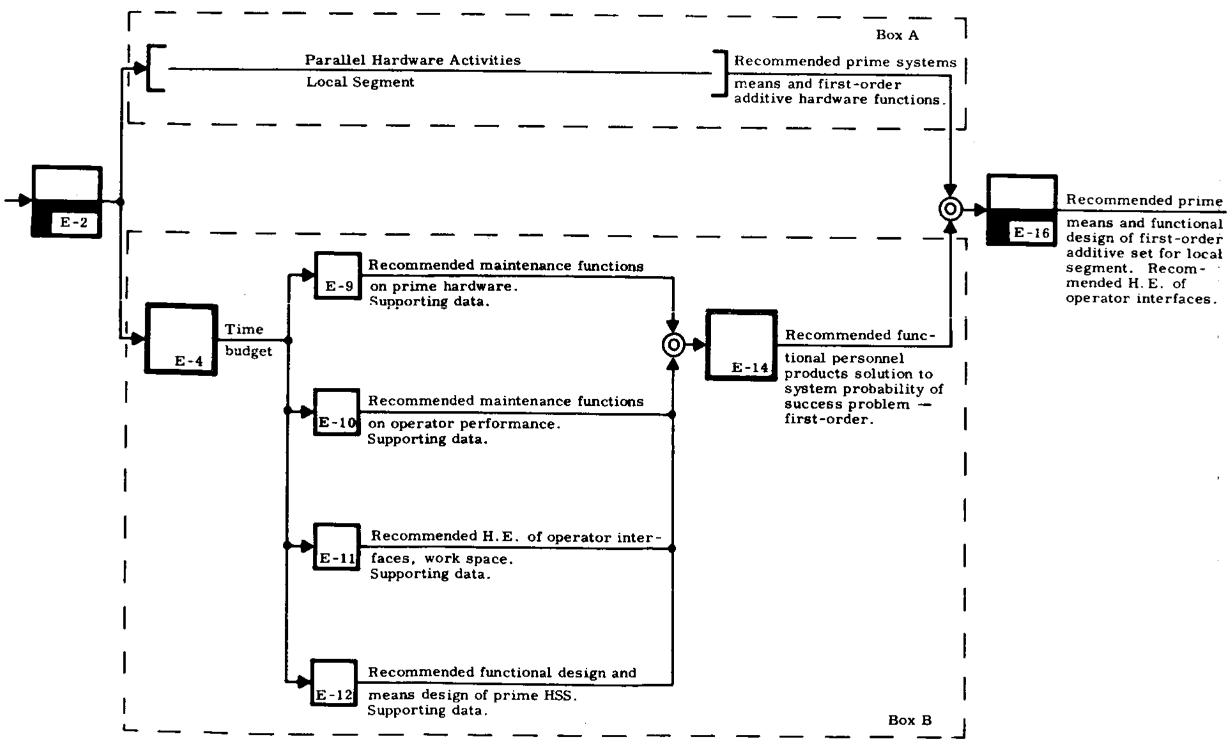
The first major requirement for this activity derives from the complexity of the personnel products area. In Function E there are four parallel personnel products activities (E-9, E-10, E-11, E-12), each of which results in multiple sets of personnel products. Activity E-4 is required to allocate requirements among these activities and to provide technical control in meeting these requirements. The second major requirement for this activity is that specific action is required to ensure that the personnel products developed in Function E are credible. This means that predictions based on these outputs with regard to probability of success of the development cycle will be valid, and that there will be no unanticipated problems in future activities of the development cycle model. Insurance of credibility of personnel products is achieved through the development of test procedures, both interim and final, in this activity (E-4). Of course, credibility cannot be assured by a test plan alone, the plan must be implemented. The requirement for providing credibility therefore applies equally to activity E-14.

In the event the output of activity E-4 is late, two possible results may occur. If a decision is made to hold up work on the following personnel product activities, there will be a general slippage in meeting the overall schedule. If a decision is made to go ahead with incomplete specifications, this will result in wasted activity on the part of the follow-on activities which will be lacking guidance as to the specific requirements which must be met. In most real-life development cycles, the latter problem is most likely to occur since staffing of the following activities has probably already occurred and the "theory is" that it is better to have these personnel work in an undirected fashion rather than to do nothing.

In the event there were no outputs from this activity, the results would be dependent basically upon the individual abilities of the personnel manning activities E-9, E-10, E-11, and E-12. It is possible that they could overcome some of the problems through self-imposed requirements based on interface agreements among the various affected activities, but it is unlikely that overall system Q and Cost goals could be achieved.

Initiating Inputs

The diagram below is a copy of that part of Function E with which this activity (E-4) is concerned. Overall, the design state which is being produced in Function E is the design of the prime equipment, and the functional design of the additive set which this prime equipment requires. The output of



E-16 in the figure is simply the <u>local segment part</u> of this design state. Activities E-16 and E-2 taken together form a technical monitoring pair which is responsible for seeing that this design state is produced, but the actual design work is done within the two dotted boxes which have been superimposed on the figure. Dotted box A represents the hardware products of this design work, and dotted box B represents the personnel products of the design work.

The responsibility for seeing that the personnel products work (box B) gets done falls to activities E-4 and E-12, which act as a technical monitoring pair for the individual personnel products activities (E-9, E-10, E-11, and E-12). Thus, as the pilot activity in the technical monitoring pair (E-4, E-12), activity E-4 is the recipient of the initiating input which gets box B going. This initiating input is a work statement which comes from the activity which has overall responsibility for the local segment, namely E-2. To be the most useful, this work statement should be a complete specification of how the <u>product</u> of box B is expected to perform. Ordinarily it should <u>not</u> be a prescription for how these products should be produced. This should be left to those who have the most contact with what is to be produced, namely the workers within box B.

The personnel products part of the output of E-16 is first of all an identification of the maintenance <u>technician</u> performance required to maintain the prime means (both human prime means and hardware prime means). Therefore the work statement which E-2 provides for activity E-4 should include a precise statement of the prime functions and the probabilities of outputs which must be obtained. This statement would provide a criterion by which to assess prime hardware plus any additive loops needed to meet probability of output goals. Certainly not all additive loops would be implemented by maintenance technician performance. Indeed, some prime performance might be implemented solely by maintenance hardware. Nevertheless, by logical deduction, the basis for testing the box B outputs can be derived from specifications of the prime functions to be implemented.

Given a list of required human performances, these provide the criterion for judging the goodness of the Human Support System which must also be designed within the personnel products part of Function E. The Human Support System is certainly as much a piece of hardware as any other hardware in the local segment. It is unique, however, in that the sole measure of its goodness may be specified by personnel products people according to the desired effect it should have on human performance. Therefore its design is placed in the personnel products package.

The personnel products group must also provide the design information required to finish the design of that prime hardware which is to be used by men (human engineering of the prime equipment). In this case, the work statement would include a requirement that those operator performances which are to be provided be articulated with hardware so that no system reliability is lost.

Thus, in every case, the work statement which E-2 provides to E-4, contains the criteria by which the outputs of box B must ultimately be measured in the operational system.

In addition to specifying this ultimate measure of goodness, the work statement may specify some practical tests which will be applied to the outputs of box B as soon as the outputs are produced. Such practical tests are just as important to E-4 as the ultimate tests, and in order to properly plan the work of D-4, these practical tests must be known in advance. Part of the practical test of the goodness of the D-4 output might be concerned with the cost of producing these outputs, and the time it took to produce them.

Method

In order to relate this activity to the existing ideas regarding methodology, it must be thought of essentially as the process of "setting up the personnel products for evaluation." Although the actual application of the evaluation does not occur until activity E-14, the planning of the tests must take place during this activity (E-4). A number of approaches have been suggested to the evaluation problem; however, they have been oriented primarily to proficiency measurement in connection with training (Glaser and Klaus)[1] or evaluation of an existing system (McCormick)[2]. An additional limitation in their applicability to the present problem is that they do not emphasize the derivation of requirements for the performance to be tested from the cost and quality goals of the system. The methodology presented below, therefore, takes advantage of existing personnel products evaluation techniques, but modifies the approach to base these evaluations on system cost and quality elements.

Task 1. Analyze personnel product requirements.[3] — The initial task in this activity is to analyze the requirements imposed on the personnel products area as presented in the output of the initiating activity (E-2). From this set of requirements, activity E-4 must in turn define the requirements which are to be satisfied by each specific activity following E-4.

The first step in this process is to analyze the requirements from E-2 and to reexpress them, if necessary, in terms meaningful to the personnel products development process. Typical elements that might be included in the set of requirements from E-2 include the following:

1. A rough statement of the prime hardware performances which must be sustained.

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[1] Robert Glaser and David J. Klaus. Proficiency Measurement: Assessing Human Performance. In Psychological Principles in System Development. Robert M. Gagne; ed. Holt, Rinehart and Winston, 1962, p. 419 et seq.

[2] Ernest J. McCormick. Personnel and System Integration, Part Six. Human Factors Engineering. McGraw-Hill Book Company, 1964, p. 569 et seq.

[3] In this section the requirements for an activity are to be thought of as the "purposes" for which the outputs of that activity are to be used. The requirements for an activity may also be thought of as the measures of goodness of the outputs of that activity. (The ultimate measure of goodness of the outputs is always: "Do they serve their purpose?" Other measures of goodness must always be derived from this ultimate measure. Thus, "measure of goodness" and "purpose" may be thought of as equivalent concepts.)

2. A rough statement of the prime human performances which must be sustained.
3. An identification of the tests on the outputs which must be passed.
4. An identification of the allowed time to produce the outputs.
5. An identification of the allowed resources to produce the outputs.
6. An identification of constraints.

Task 2. Analyze supportive data regarding operator allocations. — Supportive data developed in conjunction with earlier design work (particularly the data developed in conjunction with the allocation of operator performance in D-7) must next be analyzed to determine the constraints, such as crew size, which these earlier designs impose. In addition, the previous design activities provide a rich store of preliminary data concerning all of the personnel products that are to be developed in the course of the development cycle. Although the degree of detail in these data is not as fine as it becomes in subsequent design work, candidate solutions to personnel products problems will have been identified and tagged with preliminary cost estimates and probability of developmental success. This information must be organized so that personnel in E-4 will have available to them, in an organized fashion, estimates of the range of cost per personnel product activity linked to the probability of success.

Task 3. Preliminary specification of requirements for activities. — Eventually E-4 must specify precisely what is required of its follow-on activities. A precise specification should be in the form of a statement of how the outputs of these activities must perform. It should state what the ideal performance ought to be in the operational situation, and it should also state what this performance should be in the practical tests which will be imposed by E-4. Thus, in order to completely specify the requirements for the activities following E-4, these practical methods of testing the outputs of the activities must be known. In this task we shall neither devise a complete specification of the requirements for these activities, nor shall we devise such testing methods. Rather, in this task we must prepare an experimental specification of requirements which, although premature and incomplete, will provide a basis for devising the practical testing methods in tasks 4, 5, and 6. Then, with these testing methods identified, in task 7 we may finally devise a complete specification of the requirements which each activity must satisfy.

In task 1, the requirements which must be satisfied within personnel products as a whole were identified. In task 2, all the constraints which earlier design efforts had imposed were identified. In addition, task 2 identified and organized that part of earlier data concerning likely approaches to personnel products problems. Thus task 3 consists of the synthesizing of the information developed in tasks 1 and 2 and identifying requirements based on this information. To accomplish this, all the information generated in these tasks can be organized in matrix format with specific requirements against personnel product activities. Subheadings under the requirements entries might be potential candidates for meeting the requirements identified by the earlier design data. For example, if a particular piece of equipment could not meet specified reliability, potential candidates within E-9 (recommended maintenance functions on prime equipment) might include: repair with simple hand tools, repair with special tools or equipment, and manual replacement of the malfunctioning unit.

Having organized the requirements per personnel product in a matrix, the first step in using this matrix is to identify all relevant product activities for each requirement. For example, a requirement to perform a tracking operator task with a specified accuracy is clearly relevant to both E-10, recommended maintenance of operator performance, and to E-11, human engineering of operator interfaces. It is not relevant, however, to E-9, recommended maintenance functions on prime hardware.

Once the relevance of personnel products activities is established, the next step in completing the matrix is to roughly determine for each relevant requirement/product pair whether the listed candidates pertinent to that requirement meet or exceed the stated requirement. All candidates not meeting the requirement should then be discarded. Of the remaining candidates, all those that meet the requirement would be ordered by probability of success and cost. A quick trade-off would then be conducted to select the "optimum" combination of cost and probability of success. This candidate would then tentatively be assigned to the requirement. It should be remembered that more than one personnel product may be required to meet a specific tolerance.

The final product of this task is, therefore, a preliminary identification of the requirements imposed on each activity, and an assignment of candidate solutions to each requirement. It should be remembered, however, that assignment of candidates is tentative, and is used only to enable a "nominal" test plan for the activity outputs to be made.

Task 4. Select test and/or demonstration techniques. — In order to obtain a complete specification of the requirements for the personnel product activities in E, it remains to specify the test or demonstration techniques that will be used in measuring whether or not the actual personnel product outputs actually meet specification.

There are four general classes of test available for assignment to a particular activity output situation. These are:

1. Analytic procedures.
2. Mock-up demonstrations.
3. Simulation.
4. Field test.

Analytic procedures are essentially "table-top" or "paper" validations of the output products. Although many times analytic techniques are not as convincing as empirical techniques, frequently they are the only techniques available in the earlier part of the development cycle. Typically they involve the evaluation of human engineering drawings, analytic studies, and extrapolations of previous experimental and systems experience to the present system development situation. An interesting aspect of such evaluations is that they may be thought of as an evaluation of the methodology used to develop the personnel products rather than an evaluation of the outputs themselves. An example of this might be the output of E-9 (recommended maintenance functions) for an aerospace vehicle performing an earth orbital mission. Some of the constraints imposed on this activity would undoubtedly involve crew time available for performance of maintenance, and the time already committed to operational functions. One of the critical aspects of the analysis, therefore, would be crew time required to perform maintenance on the equipment which requires maintenance to meet mission requirements. At the present time, the only source of such data are zero-gravity earth simulations. The evaluation of the outputs of this activity would consist, therefore, in an evaluation of the appropriateness of the experimental studies selected for extrapolation, and the analytic processes used for extrapolation to the system situation. It is assumed, of course, that the outputs indicate that the maintenance can be performed within the allowable time. The criteria applied in the testing of this output is usually not thought of as directly derived from the system cost and quality elements. Rather, it is thought of as derived from more general criteria of analytic validity and is related primarily to the probability of developmental success, and, of course, operational mission success.

Mock-up demonstrations include the use of both static and functional mock-ups for the demonstration of the validity of particular personnel product outputs. The use of such devices is particularly appropriate to the area of human engineering of operator interfaces (E-11). The only limitation on their use in Function E is that such mock-ups would have to be constructed after the completion of the selection of hardware means. This probably limits the use of such mock-ups in Function E primarily to static mock-ups that can be quickly constructed of cardboard and similar materials. One of the major advantages of mock-ups in the real world which includes managers, is that they demonstrate in three-dimensions the validity of outputs from personnel products regarding the physical layout of the local segment, e.g., arm reach to critical controls and location of displays within the visual field. Their use should be seriously considered even in such an early function as E, since they are of value even when they show only the general layout of major equipment units when final decisions have not yet been reached on the layout of displays and controls on console panels. A further advantage of the use of mock-ups for demonstration of the validity of personnel product outputs is that they come a significant step closer to operational empirical data, even without the actual operational mission environment.

Simulation as a technique for the evaluation of personnel product outputs includes both operational simulation, with man in the loop, and computer simulation using a model of the operational situation, without man actually participating. Operational simulation, with man participating, is usually not appropriate at the period in the development cycle represented by Function E. It is almost mandatory, however, when personnel products are tested at a later point in the cycle, particularly in Function H, when the final personnel products are about to be inserted in the operational system. It is not too early to consider the use of simulation models in Function E. A good example of such simulation is the use of a computer simulation model to test the outputs of activity E-9 dealing with the allocation of maintenance functions to the crew. Such models have been successfully used to predict the maintenance load that can be imposed on man under given mission situations thus testing the validity of the allocations under critical conditions. Such evaluation may indicate that allocation of certain maintenance functions to man is feasible only if no concern is given to the operational functions of the mission.

Field test of personnel products can only be accomplished after there is at least a prototype operational system in existence that can be tested under actual operational conditions. An example of the utility of such testing is seen in the programmed orbital missions in the Apollo program, prior to the lunar mission. Such testing, of course, would be associated with Function H in the development cycle model.

Selection of the appropriate technique for testing a specific personnel product may initially be based solely on technical considerations. It can then be traded off against cost factors. The integration of devices and equipment required for conducting the testing program, e.g., combination of personnel products requirements with hardware testing requirements, is a management function done by activities E-2 and E-12, and is not discussed here.

Task 5. Develop test plan. — After the tests and demonstration technique have been selected for each specific personnel product, they must be integrated into an overall test plan. This plan should be integrated first at the level of the individual personnel product activity, and then integrated across activities. It should be understood that the developed test plan resulting from this activity is itself preliminary in nature, and will be modified with the experience gained during the performance of the various personnel product activities. The components of such a test plan should include the following categories, which are based on previous system studies.

1. Test objectives. This section should specify the products to be tested, and should precisely identify target scores for each (derived from Cost and Quality formulas).

2. Ground rules. A specification of what personnel from the packaging group will be involved in the testing, their functions and responsibilities, and any support required from the personnel product activity concerned.

3. Subjects. If the test includes the use of subjects, e.g., walk-through of procedures in a mock-up, the number of subjects required and any special qualifications should be specified.

4. Data collection personnel. The number of personnel required as observers at the test, who will supply them, and any special qualifications will be detailed in this section.

5. Schedule. The calendar dates and sequences of the data will be listed in the portion of the test plan.

6. Procedures. The specific procedures to be carried out in the test will be presented and related to the test schedule. This section of the plan will probably not be available with the initial publication of the plan since it will be dependent partly on the results of the activity of concern.

7. Test design. This section should identify the rationale which links the actual test procedures to the test objectives. If appropriate, the proposed data analysis should also be presented. Finally, the equipment or instrumentation requirements should be identified.

8. Integration. The final section of the test plan should relate the various personnel product tests to the overall test plan for the function of concern, in this case Function E.

Task 6. Plan the phi function. — The phi function is the extension of activity E-4 that covers the period of time between the output of specifications from activity E-4 until the implementation of the test portion of those specifications in activity E-14. This function is required to maintain effective technical control over the various personnel product activities. Discussion of this function has been arbitrarily divided between activities E-4 and E-14, with the planning portion covered in this section, and the implementation of the function covered under activity E-14.

Planning of the conduct of the phi function should include consideration of the following five areas of activity:

1. Interim testing. To avoid out-of-tolerance conditions in the final testing described above, interim testing should be conducted throughout the life of the personnel product activities. This testing might be similar to that specified for final testing modified, either through reduction in the thoroughness of the testing or reduction in the scope of the testing, by appropriate sampling techniques for selection of interim products for testing.

2. Technical support. Interim testing is concerned with whether or not the personnel products are meeting specification as they are developed. Technical support is concerned with obtaining correction of deviations revealed by interim test results.

3. Interface control. The interface control of concern here is between people rather than between hardware units. Two types of control are required for effective functioning of the personnel products group. First, there must be control of interface among the various personnel product activities. Second, there must be adequate and effective interface with personnel responsible for hardware development (in Function E those charged with the responsibility of selecting hardware to implement the functional design of the prime system). This control should be exercised through the establishment of procedures for

interface contacts, maintenance of records of such contacts and their results, and, finally, by participation in meetings.

4. Trade-off studies. The personnel products packaging activity group is responsible for monitoring and serving as arbiter and decision-maker for trade-off studies involving personnel products. This is true within the personnel products area, but not between the personnel products and hardware areas. The conduct of this responsibility is similar to that described for interface control.

5. Requirements reallocation. The packaging activity should develop plans and techniques for reallocation of requirements imposed on the various personnel products activities. Such reallocations may be required because of unanticipated technical problems, breakthroughs in the state of the art, or because of inappropriate allocations by the packaging group initially.

Task 7. Specification of requirements. — Once the complete test schedule has been devised in tasks 4, 5, and 6, we may specify completely the requirements which E-4 must impose on the individual personnel products packages. These requirements on each activity actually form the initiating inputs for that activity and tell it how its outputs are to be judged. Thus each activity must be told how it fits into the overall test plan, and specifically what tests are in store for its outputs. Included in the specification of requirements for an activity is the identification of the complete set of constraints which it must observe. These include constraints on time and money, on weight, power, and volume, and on man-hours available from the crew to perform whatever functions an activity might identify. In addition, specification of requirements will include an identification of the ultimate purpose in the operational system of each of the activity's outputs.

Ordinarily, the candidate solutions to the personnel products problems which were identified and used by activity E-4 to enable the preparation of a test plan are not intended to constrain the activities to use these candidate solutions. Certainly, all the information which has been generated earlier is available to the activities, but is not intended to restrict their search for more information and better candidate solutions. In fact, the whole purpose of each individual activity is to search out and find the best solutions to its assigned problems. It would defeat the purpose if earlier (and not as good) solution candidates were forced on them.

Activity E-14 (Local)

Outputs

The output of this activity is a recommended functional personnel products solution to the system probability-of-success problem. This recommended solution is based on verified and integrated personnel products resulting from the personnel product activities contained in Function E (E-9, E-10, E-11, E-12). In addition to this primary output, activity E-14 will also provide a supportive data package containing the results of the verification tests performed on personnel products.

Requirements

The requirements for this activity are similar to those for activity E-4; namely, to provide technical control, integration, and verification of the various personnel product activities contained within Function E. In addition, the specific requirement for this activity is to provide the implementation of the final test of the personnel products.

In the event the output from this activity is late, this would cause a general schedule slippage of Function E since it would be a difficult, if not impossible, task to effect meaningful integration in activity E-16 if the personnel package were not available. If the output of E-14 were of low quality, it would reduce the credibility of the functional solution and increase the possibility of problems later in the development cycle. If the output of this activity were entirely missing, the only alternative available to following activities, specifically E-16, would be to utilize the unverified outputs of E-9 through E-12 and attempt to integrate them into a meaningful whole. This again would jeopardize the success of the development cycle by utilizing low credibility data with unknown consequences. In either the case of low quality or missing outputs there would also be considerable danger of cost overruns.

Initiating Inputs

If E-4 and E-14 are viewed as part of one big function, (E-4, E-Φ, E-14), the initiating inputs for this activity are the same as those for E-4. Thus the initiating input for this activity is the work statement which comes from activity E-2, in which the required performance from E-4 and E-14 is specified. Alternatively, in the "Go" model, the outputs of E-9, E-10, E-11, and E-12 are the initiating inputs.

Method

The methodology for this activity is largely determined by the planning accomplished in activity E-4. Essentially the methodology for this activity consists of implementing (with modifications as required) the control and verification program defined in E-4. This implementation encompasses four tasks.

Task 1. Implement the phi function. — The phi function is implemented in parallel with personnel product activities E-9 through E-12 since it must integrate and control these activities in real time. As indicated in the discussion of activity E-4, this function includes the following:

1. Conduct interim testing.
2. Technical support.
3. Interface control.
4. Trade-off studies.
5. Requirements reallocation.

Since the plans for performing this function were previously established, implementation will consist of applying the plans and techniques to the operating situation. Modification will undoubtedly be required as problems are encountered in personnel product activities and in the control techniques employed. In addition to the listed items, there will be continual updating of the final test plan to ensure that the test program can be initiated on schedule immediately following the output from the various personnel product activities.

Task 2. Conduct final verification tests. — Again, this is an implementation of plans developed in activity E-4 and updated in task 1 above. Final testing will include tests of single personnel product activity outputs and integrated products as appropriate. In many cases there may actually be no additional testing of products required in this task, since testing accomplished within the activity itself will be monitored and may be acceptable as final verification of the products.

Task 3. Analyze and integrate results. — This task includes the analysis of test results conducted under task 2 and the integration of these results into a recommended function personnel products solution of system success for the first-order additive set. A complete matrix of requirements by personnel product solutions can serve as the primary integrating technique for this task. If all products are within tolerance, then it is simply a matter of entering the obtained results in the appropriate cells of the matrix. In the event that obtained results exceeded expectation, this data should be flagged and used for potential reallocation of requirements in the follow-on functions. In the event that any of the products fall below specification, then task 4 below will be required.

Task 4. Retrofit. — If any of the personnel products fall below the specified requirements, it will be necessary to conduct retrofit activities. These activities may be visualized as additional personnel product activities added to the development cycle model. The first of these activities might be a capsule version of whichever of the personnel product activities has developed the faulty product (E-9 through E-12). The second activity would be a corrective activity (E-14). Hopefully, the extent of work in each of these added activities would be significantly less than in the planned activity. This assumes that the fault concerns only a partial product of an activity rather than a total failure. It further assumes that not all of the testing and integration conducted in E-14 would have to be repeated, but rather the new test data could be integrated into the original functional recommendation.

Selection of Personnel Products in the Additive Set
Activity F-4 (Local)

Outputs

The outputs of this activity are the specifications of requirements that must be met by the personnel products resulting from activities F-8 (maintenance of technician performance), F-9 (design of maintenance interfaces), and F-10 (performance on maintenance and Human Support System equipment). In addition to specifying and allocating cost and quality elements to these activities, the outputs must also specify the tests and demonstrations to be used in determining whether or not the outputs meet specification.

Requirements

The primary requirement, as was the case for activity E-4, is to ensure that a personnel products solution for the maintenance system and maintenance interface problem is achieved within target cost and quality. It is also required to maintain technical control over these activities to ensure that there are no schedule slippages resulting from inappropriate solutions which are not detected in a timely fashion.

Initiating Inputs

The initiating input for this activity is the output from activity F-2 which specifies to activity F-4 the requirements that must be met within the personnel products area, both with relation to quality and cost. This output from F-2 represents the same kind of requirements information provided by activity E-2 to E-4, as modified by the activities contained within Function E.

Method

The methodology required for accomplishing the activity is the same as that discussed for activity E-4. At this point in the development cycle there would be little significant change, for example, in the types of testing that could be employed in verifying the personnel product activity outputs.

Activity F-12 (Local)

Outputs

The primary output of this activity is the recommended maintenance system and maintenance interface design. This output goes to activity F-14 for integration into the recommended complete additive set for the local segment. In addition to the prime output, supportive data resulting from the verification process as well as the outputs from the preceding personnel product activities will be provided.

Requirements

The requirements for this activity are based on the need for credibility estimates of the validity of the personnel product solutions to the maintenance system problem. These credibility determinations are necessary to predict the probability of success of the development cycle.

Initiating Inputs

The initiating inputs for activity F-12 are the outputs of F-8, F-9, and F-10.

Method

The method employed in this activity is the same as that discussed for activity E-14. Methodology is relatively straightforward in this activity since it is primarily an implementation of plans developed in activity F-4.

Preparation of Fabrication Tools and
Models for Personnel Products
Activity G-4 (Local)

Outputs

The primary output of this activity is an allocation and specification of requirements based on cost and quality objectives for the crew package controlled by activity G-6 and for the Human Support System, activity G-16. This output must also include the specifications for the tests and demonstrations that will be used to verify whether the personnel product outputs are within specifications.

Requirements

The requirement for this activity is the same type as that for E-4 and F-4. It is to provide effective allocation of requirements among personnel product activities, and provide technical control over the attainment of these requirements.

Initiating Inputs

The initiating input for this activity is the output from activity G-2 which specifies the requirements that must be met by the personnel products package in developing fabrication plans and tools.

Method

There is a departure in the methodology appropriate to this activity from the pattern of activities E-4 and F-4. This results from the fact that the personnel product activities accomplished in Function G have been grouped into two units. The man package (G-12, G-13, G-14, G-15) is bounded by activities G-6 and G-18 which are similar to the packaging activities of E-4 and E-14 in Function E. The Human Support System is covered by activity

G-16. Because of these intervening activities it is no longer necessary to make specific allocation of requirements to specific personnel product activities. Rather, the allocation is made by this activity between the man package and the Human Support System package. This change also affects the planning of the phi function since this function will now be used to monitor only the operations within G-6, G-16, and G-18, rather than all personnel product activities contained within Function G. This change in effect introduces an additional layer of technical management and control into the personnel products packaging activity. A final change in methodology for this activity over previous similar activities is that, at this point in the development cycle, there is greater potentiality for use of more sophisticated testing tools, particularly the use of simulators with man in the loop.

Activity G-20 (Local)

Outputs

Thr primary output of this activity is the recommended fabrication plan and tools for all personnel products. This output is utilized by activity G-22 to develop the total fabrication plan and tools for the entire local segment. In addition to the primary output, a supportive data package will be provided covering the results of the verification testing of the various personnel products and the analytic integration of these results.

Requirements

The primary requirement for this activity is to accomplish the testing and integration of personnel products resulting from the various activities so that a determination can be made of the probability of success of the development cycle with reference to the personnel products area.

Initiating Inputs

The initiating inputs for this activity are the outputs of G-18 and G-16.

Method

As indicated above, the separate testing of personnel products has been completed prior to initiation of this activity. The testing still to be accomplished in this activity, therefore, is the total integrated testing of the personnel products package for Function G. Again, this type of activity is essentially an implementation of plans made in a preceding activity (G-4). The only significant change over previous similar activities is in the level of sophistication of the testing employed (e. g. , simulation) and the consequent increase in time and staffing required to accomplish the test program.

Fabrication of Personnel Products
Activity H-4 (Local)

Outputs

The output from this activity is an allocation of requirements for the personnel products activities specifying the cost and quality elements that must be met in the output from these activities. The allocated requirements are split between the man aspect of the personnel product package and the Human Support System. The specification must also include the proposed testing of personnel products that will occur in activity H-16.

Requirements

The primary requirement of this activity is to ensure that the final fabricated personnel products package meets all cost and quality elements of the requirements imposed on the personnel portion of the system. The output of this activity, therefore, must provide technical control of the various personnel product fabrication activities.

Initiating Inputs

The initiating input for this activity is activity H-2 which specifies the requirements that the total personnel products package must meet with reference to cost and quality.

Method

The methodology applicable to this activity is the same general method discussed under activity E-4, as modified in activity G-4, since again there is the single split between man and human support activities without detailed technical control of the activities that make up each of these technical areas. One shift in method for this activity is the requirement that tests proposed in this activity represent the final testing phase before actual system operation. This requirement suggests that the greatest degree of sophistication of testing be planned within the limits of cost. In effect, the tests planned in this activity certify that the personnel products package, selected and trained personnel, job aids, and material in support of human performance, as well as the Human Support System are ready for installation in the system.

Activity H-16 (Local)

Outputs

The output of this activity is the complete personnel products package ready for integration with the hardware units in activity H-18, and installation in the system in activity H-19.

Requirements

The requirement for this activity stems from the basic requirements of the need for the system and for verification that a major segment of that system, the personnel products package, is ready for operation in that system.

Initiating Inputs

The initiating inputs for this activity are the outputs of H-12 and H-14.

Method

The method for accomplishing this activity is similar to that of preceding verification activities. The only difference is the criticality of this test in that once certified for the system, there are no additional tests and possibilities for retrofit within the development cycle. The only retrofit after this activity comes as a result of a malfunction in the operational system, or a mission abort. The implication of this criticality is that quality control of the test situation should be intensified to the limits of available resources. There is also greater possibility for error in the test situation, since this represents the most sophisticated test in the whole development cycle.

VI. DETERMINATION OF MAINTENANCE PERFORMANCE (ADDITIVE FUNCTIONS) TO BE CARRIED OUT BY MAN

Activity Group Requirements and General Considerations

It is a fact that every aerospace system must include an additive set. In every system the additive set is included purely for the purpose of achieving target overall system probability of success. Every function in the additive set must be justified in terms of its positive contribution to the probability of system success; else, it must not be included.

The elements in the additive set for any system are additive loops, each of which is composed of a connected sequence of functions. One subset of additive loops will consist of those functions which act directly upon prime system means. Another subset will act upon the means in the first subset, and so on for as many orders of subsets as desired.

If we consider the subset of additive loops which acts directly upon prime system means, we may note that some of them will act upon prime system hardware and some will act upon operator performances. Similarly, in the other subsets of additive loops some of the additive loops will act upon maintenance hardware and some upon maintenance technician performance. In this chapter, we are concerned only with those additive loops which act directly upon hardware, whether it is prime hardware, or maintenance hardware, or personnel support system hardware.

If we consider further those additive loops which act upon hardware, it will be seen that some of the functions in these additive loops will be implemented by means of maintenance hardware and some will be implemented by means of maintenance technician performance. Because it is not within the state of the art to develop aerospace systems that do not require maintenance technician performance for the purpose of sustaining hardware performance capability, it is necessary in the course of developing every aerospace system to decide what maintenance technician performances will be employed. In this chapter, we are concerned with those activities in the development process that bear directly upon determining the maintenance technician performances to be employed. Because maintenance technician performances are employed in additive loops to contribute to the reliability of implementation of system functions, we will be concerned directly with the probability-of-success requirement in the system Quality score formula. In assigning to man the responsibility for carrying out additive performances, it will be necessary to consider the probability-of-success factor jointly with cost, to assure that the decisions which are made will not drive the total system solution out of the target Cost, Quality area for the system.

In general, man performance will be employed in additive loops in three different ways: (1) man performance will be employed as a standby redundant means to take over where hardware fails; (2) man performance will be employed to carry out corrective maintenance activities to restore hardware capability when it is lost; and (3) man performance will be employed to carry out preventive maintenance to preclude hardware failure.

The need for care in the process of allocating maintenance technician functions to man is most stringent in the case of the local segment. Weight, power, and volume limitations, and the separation of the local segment from logistic sources and from second- and third-order additive backup place severe demands upon the designer, who must employ maintenance technician performance within severe limitations for the achievement of very high levels of reliability. It may be said overall that the success of the designer in this regard may be measured by determining whether or not he achieves target system probability-of-success goals.

Relationship of the Group to the Development Cycle Model

The group of activities under discussion in this chapter includes two activities of Function E; E-5 which produces an identification of the remote system maintenance technician performance required on prime hardware, and activity E-9 whose output contains similar information for the local segment.

The group also includes two activities in Function F. The first is activity F-7, whose output is an identification of maintenance technician performance on the Safety and Support System and maintenance technician performance necessary for maintaining remote maintenance equipment. The second is activity F-10, which produces a recommendation for the use of maintenance technician performance to maintain the Human Support System and to maintain maintenance equipment in the local segment. Taken together, these four activities plus D-4 and D-7 identify virtually all of the functions to be allocated to man in the local and remote segments.[1]

In the case of activities E-5 and E-7, which are concerned with the remote segment, limitations on the types and number of personnel that may be used are normally not severe. Allocations can be made on the basis of the best use of man. In the case of activities E-9 and F-10, however, allocations of maintenance performance will have to be made within the limits of the crew size established in Function D. Therefore, in designing for the local segment, deliberate care must be exercised to consider all of the other activities which may demand crew time, and calculation must be made to show that recommended allocations of maintenance technician performance do not carry with them attendant violations of limitations on weight, power, and volume.

It can be seen, then, that activities D-4 and D-7 establish the framework within which the activities in this group must be carried out and that the limitation established in the case of the local segment may be quite severe. Each of these four activities is carried out in immediate response to a requirement statement from a personnel products technical management activity, and the output of each is received by such an activity. Thus, for example, activity E-9 is initiated by a requirement statement from activity E-4 identifying the weight, power, and volume budget for activity E-9, and allocating the proportion of personnel resources which may be given to maintenance technician performance. The output of activity E-9, identification of functions in the

[1] Other activities which identify functions to be allocated to crew members include those concerned with the maintenance of operator performance, the maintenance of maintenance technician performance, operation of the personnel support systems, and use of job aids.

additive loops on prime hardware to be implemented by maintenance technician performance, is received by activity E-14. In E-14, the recommended use of maintenance technician performance is integrated into the personnel products package on the basis of the supporting data for the recommendations which are also provided by activity E-9. It can be seen from consideration of the symbolic model that activities E-5, F-7, and F-10 are similarly bounded.

The recommended allocations of maintenance performance on prime hardware are stabilized in the output of Function E, and the recommended use of maintenance technician performance to maintain maintenance equipment and to maintain the personnel support systems is stabilized in the output of Function F. These data find their principal employment in activities G-5 and G-6 where the jobs for each crew member are finally stabilized. Thus, these data which identify maintenance technician performances to be allocated to man become the basis for job makeup and, in turn, bases for identifying requirements for job aids, training, and selection. Finally, the data are employed as a basis for evaluating the crew package in Function H. Thus, in evaluating the crew packages, a demonstration of capability to carry out required maintenance technician performances is necessary.

Resources Needed

The group of personnel who will be required to work on tasks related to the identification of maintenance technician functions begins to form early in system development. The development cycle personnel who are concerned with the prediction of likely maintenance technician performance in D-4 and D-7 may be thought of as forming the core of the group of personnel who carry out the work in E-5, E-9 and F-7, F-10. In activities D-4 and D-7, where operator performance allocations are recommended, this core group must be capable of assisting in providing data which show that the maintenance technician functions which will later be required can be implemented within the man-hours remaining to the crew after their prime functions have been accomplished. When it is time to identify the prime hardware maintenance functions in E-9, this core group may form the nucleus of the personnel to implement this task for they will have considerable relevant experience.

Whenever a group of development cycle personnel are involved with identifying maintenance technician functions, there are certain skills which they must have. For example, given the design of a piece of hardware, they must have the capability for deducing the state-of-the-art maintenance strategies which could be used to achieve the desired reliability, and they must be able to identify the maintenance technician functions which such strategies imply. In addition, when a set of maintenance technician functions for that piece of hardware has been identified, they must have the capability for accurately estimating the likelihood that these functions can be implemented, and the cost of training people to implement them. Furthermore, they must have the capability for deducing the weight, power, and volume implications which the means for implementing identified maintenance technician functions hold.

The equipment needs of this kind of development cycle personnel may simply be desk space and a good library. On the other hand, since the literature on the identification of maintenance technician functions is by no means complete, and since in a complex and expensive aerospace system this identification can be critical, there may be a need for exploratory design and fabrication of equipment to find out on the spot what the various implications of the development decision are with regard to the identification of these functions. It is likely also that the testing of maintenance strategies will involve use of data-processing equipment.

Identification of Functions in Additive Loops on Prime Hardware to be Implemented by Maintenance Technician Performance Activity E-5 (Remote)

The output of this activity is one of the bases for achieving a stabilized means selection for the prime system and a stabilized function design of the additive set in the output of Function E. To serve this purpose, it must include identification of the functions in the additive loops for prime hardware that should be implemented by maintenance technician performance in the remote segment. It should also provide supporting data germane to the recommendation which can be employed as a basis for modifying the recommendation, or for demonstrating that acceptance will not lead to future problems in the design and fabrication of the system.

The input to E-5 will be a requirement statement from activity E-3 identifying any constraints within which maintenance technician performance allocation must be made, and identifying the manner in which activity E-5 will be evaluated. The essence of evaluation will be a demonstration that every allocated maintenance technician performance contributes to overall system probability of success, that the probability-of-success goals are achieved, and that no more desirable solutions can easily be found.

Activity E-9 (Local)

The output of this activity is similar in content to the output of activity E-5. The output of activity E-9 relates to the local segment, however, and must take into account constraints of weight, power, volume, and crew size. Thus, the recommendations with respect to allocation of maintenance technician performance must fall within crew size limits, and the supporting data must show that the use of crew time is compatible with other needs for crew time. The supporting data must also show that implications of the recommendations upon weight, power, and volume use are justifiable. Data should be presented to enable any adjustments in recommendations that might be required at the personnel products package level, at the local segment level, or at the system level.

The initiating input derives from activity E-4. It is similar to the input to activity E-5 except that it includes limitations with respect to weight, power, volume, and crew size. The evaluation of activity E-9 (specified in its input) will therefore call out the criteria by which the use of weight, power, volume, and crew size will be evaluated.

Recommendation of Maintenance Technician Performance for the Maintenance of Maintenance Equipment and the Safety and Support System Activity F-7 (Remote)

The output of this activity is an identification of all of the maintenance technician performance allocations recommended for the remote segment, and recommendations with respect to the technician performance required for the maintenance of the Safety and Support System. Inasmuch as maintenance technician performance in first-order additive loops will have been identified in activity E-5, what is added in activity E-7 will be second-, third-, and lower-orders of additive performance to be assigned to man. Supporting data which demonstrate that the recommendations are consistent with the achievement of a satisfactory system solution must also be provided.

The input derives from activity F-3, a personnel products technical management activity. The input will be in the nature of an order to determine maintenance technician performance allocations. First-order maintenance technician performances will be identified and the manner in which activity F-7 will be evaluated will be stated.

Recommendation of Maintenance Technician Performance for the Maintenance of Maintenance Equipment and the Human Support System Activity F-10 (Local)

Performance of this activity must be within constraints of weight, power, volume, and crew size. The output will contain the same type of information as that required for activity F-7, but the supporting data must demonstrate that justifiable use of weight, power, volume, and crew time has been recommended.

The input derives from activity F-4. This input is analogous to the input to activity F-7. In addition, however, it identifies the limitations on the personnel products package for the local segment.

Discussion

Within this activity group, activities E-5 and E-9 form a subset that is distinct from the subset composed of F-7 and F-10. The activities in Function E are oriented toward identifying the crew performances required to implement additive loops on prime system hardware. The objective of the activities in Function F are not quite so clear cut. Basically, what is required of F-7 and F-10 is that they identify all of the maintenance technician performance of crew members not previously identified. Taken together, then, the outputs of E-9 and E-5 plus the outputs of F-7 and F-10 identify all maintenance technician functions. We will discuss activities E-5 and E-9 first.

The performance of activity E-5 requires close interaction with the parallel hardware-oriented activities. Activity E-5 must not only interact with those activities concerned with identifying hardware means for the remote segment; it must also interact with the activities concerned with identifying means and additive loops for the local segment. Activity E-5 falls in the chain of activities that is concerned with the remote segment. It becomes involved with the local segment simply because some of the additive loops on prime local hardware will be implemented when the remote and local segments are coupled, and at that time it is most likely to be the remote crew that will carry out the maintenance actions on the local segment rather than the local crew. In general, it can be predicted that it will be advantageous to assign maintenance functions to the local crew only after separation of the local and remote segments.

In Function E, work in the hardware-related activities will be focused upon achieving a joint resolution of the functional design of the additive loops and the identification of the prime hardware with which the additive loops will be associated. The joint determination of prime means and functional designs for additive loops permits trade-offs to be made such that the prime means plus additive loop combination will be the best as a combination for each function; it will preclude the selection of means which give rise to unduly difficult maintenance problems.

In order to forestall the belated discovery of difficult maintenance problems after a firm assignment of prime means, it will be necessary to consider the functional design and the possible means designs for additive loops for alternative candidate prime means for each prime function. The functional design of additive loops does not necessarily require the consideration of personnel products problems; however, the selection of additive loops which can be implemented within the limits of freedom given to a designer can be accomplished with assurance only when there is a thorough investigation of the implications of each suggested functional design. Therefore, the development of recommendations with respect to the additive loop functions that might be allocated to crew members for performance should be carried out jointly with the selection of prime hardware means; it should not be done after the fact of means selection.

In activity E-5, the identification of functions to be implemented by maintenance technician performance can usually be carried out without any severe limitation on the numbers of personnel generated as a consequence. In activity E-9, such is not the case. In the output of Function D, the crew size for the local segment is stabilized, and the selection of functions to be allocated to crew members must be thoroughly justified as an optimal use of available crew time. Further, there will be a weight, power, and volume budget for the local segment, and it will be necessary in activity E-9 to study thoroughly the consequences of recommendations with respect to maintenance technician performance. Study must show that weight, power, and volume problems are not engendered as second- and third-order consequences of the assignment of maintenance technician performances.

Basically, what is required in the output of Function E is that the prime means for the system be stabilized and that a functional design of the additive set for each segment be so well justified by a study of ways in which it can be implemented, that the functional design can be stabilized with confidence. Data with respect to maintenance technician performance in the additive sets are required as one basis for achieving the needed confidence. The overall criterion in selecting each means plus additive loop combination will be to provide for satisfying the target probability of output of the functions implemented by the means. Every assignment of maintenance technician performance will therefore be justified in terms of its contribution to reliability of the prime means plus additive loop combination with which it is associated.

Activity F-7 is essentially a "clean-up" activity with respect to maintenance technician performance in the remote segment. Function F is designed to achieve the identification of all maintenance means at all levels in one overall exercise. Means in first-order additive loops will be selected simultaneously with the selection of means for all lower orders of additive loops. The basic decision with respect to maintenance means (hardware) to be selected will be made by the hardware package activities. In each case, the criteria for selection will be probability-of-success criteria, and no second- and third-order additive loops will be provisioned except where necessary to achieve target output probabilities. As each necessary functional design is considered, it should be evaluated in activity F-7 for the purpose of determining which component functions should be allocated to maintenance technician performance. In general, the remote segment will not be severely limited in crew size; cost and human capability will therefore be prime factors in determining what functions should be implemented by means of maintenance technician performance.

In the model, activity F-7 includes the determination of the maintenance performances in the Safety and Support System to be allocated to man. The joint consideration of all allocations at once is to enable preliminary consideration of job structures in deciding what functions to assign to man. It can be expected that some of the basic capabilities required for the maintenance of the Safety and Support System will be the same as those required for other hardware.

In activity F-10, designers will not have the freedom to call upon crew members to perform maintenance tasks without regard for the size of the crew that is generated. Rather, all recommendations must be justified as being a good use of available crew time. Full study of the implications of maintenance decisions with respect to logistics and consequent personnel products problems is required in F-10. F-10 is also charged with the task of determining what maintenance technician performances will be required to provide for reliable Human Support System performance. Because of weight, power, and volume limits, it will be necessary to look ahead and predict what job aids and material for maintaining maintenance technician performance will be needed as a consequence of assigning responsibility for maintenance to local crew members.

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VII. PROVISION FOR OBTAINING RELIABLE IMPLEMENTATION OF FUNCTIONS ALLOCATED TO MAN (ADDITIVE LOOPS ON HUMAN PERFORMANCE)

Activity Group Requirements and General Considerations

The previous chapter is concerned with determining what man must do in an aerospace system to augment the inherent reliability of hardware means so that the probability of output requirements placed on component functions of the system can be met. In this chapter, we will be concerned not with the maintenance of hardware, but with the maintenance of the capability of crew members to perform reliably the tasks assigned to them. The coverage in this chapter is not precisely analogous to that of the previous chapter, because we are here concerned with the complete additive loop by which probability of output requirements are met for functions assigned to man for implementation. Thus, we are here concerned with what man must do to maintain man performance and with the special equipment which must be developed and delivered for this same purpose.

In this chapter, we will be concerned with additive loops which must be incorporated into the functional design of the system to provide backup for operator performance, and with additive loops which are included to provide backup for maintenance technician performance. Inasmuch as we are concerned with additive loops, it will be clear that the single criterion for making provision for the maintenance of human performance capability will be overall system probability of success.

A probability equation which describes the manner in which the component functions of a system generate the overall probability of success of the system does not discriminate between functions which are implemented by man and functions which are implemented by hardware. Failure to meet target probability-of-output goals in the case of man-implemented functions has the same effect on overall probability of system success as it would if the functions were implemented by hardware. In this chapter, we recognize that the laws of chance are insensible to means and we will attempt to give the same serious consideration to providing for additive loops to support human performance as we would give to the task of providing additive loops to back up hardware performance capability.

As in the case of hardware, human performance may be backed up in three different ways to provide for the satisfaction of target probability-of-output goals. Human performance may be used in a standby redundant manner to be slipped into place when other human performance capability fails; hardware backup may be employed in precisely the same manner to back up operator performance. Human performance may also be sustained by preventive maintenance techniques. And finally, corrective maintenance techniques may be employed to back up operator and maintenance technician performance capability. What is required in a system development cycle is that objective attention be given to the task of provisioning a subset of the additive set which is focused upon sustaining reliable operator and maintenance technician performance capability. The implementation of this subset of the additive set in general requires not only the training of crew members to carry out maintenance actions on themselves, but also the fabrication and delivery of "hardware" which can be used directly to back up human performance and which is needed to assist in carrying out corrective and preventive maintenance actions such as simulators to enable practice on the job.

Relationship of the Group to the Development Cycle Model

There are basically two lines of development for the materials to maintain operator and maintenance performances. One of these is for the local segment and one is for the remote segment. While the end products of these two lines of development are not physically the same, the sequence of events which leads up to their creation during system development is essentially the same. For this reason, we will discuss only the local segment line of development, but those idiosyncrasies associated with the remote segment for any one point in the development sequence will be noted and explained as they arise. The activity group for the local segment consists of four activities, identified on the system development model as activities E-10, F-8, G-14, and H-11.

(Those parallel activities concerned with the remote segment are E-6, F-5, G-9, and H-9.)

In addition to the above-named activities which are directly involved there are others which indirectly relate to performance maintenance means (PMM) production. In the model, these other activities are primarily concerned with outputs which are not PMM outputs, as such. PMM development begins during activity D-7, where it must be shown that the recommended allocation of operator functions will not create design problems when PMM activities are reached. In order to make this kind of demonstration, there must be a fairly detailed prediction of the types of PMM that will be required to complete system design and fabrication. Prediction must be detailed enough, for example, to permit an estimate of weight, power, and volume allocations for the local segment which should be made to allow for the PMM part of the personnel products package. (Such limitations do not usually apply to the remote segment.) Consideration of PMM in activities D-7 (and D-4) thus encompasses all of the activities in the activity group. However, it does this in a predictive and representative manner on the basis of less information and in less time than would be available for the accomplishment of the activities themselves.

In Function E, more detailed anticipatory study of PMM requirements to support maintenance technician performance would take place (activity E-9). In each case, the PMM planning that is done is for the purpose of generating confidence that it is safe to proceed with design. The planning is not for the purpose of constraining the decisions that will be made in subsequent activities. Activity F-8 follows E-9 and is concerned with PMM for the performances called out in E-9. F-8 also sets forth representative plans for handling the PMM problems engendered by second- and third-order maintenance considerations and demonstrates that the problems can be solved within constraints. Activity F-8 thus produces means design of PMM for both operator and maintenance performance.

Activity H-11 delivers PMM which, in the real world of system development, will be required to undergo several adjustments before they are finally delivered and installed as part of the operational system. The key activities in which adjustments may take place are activity H-14, in which the trained crew and PMM are integrated into an operational package, and activities H-16, H-18, H-19, and H-20 which are concerned in sequence with the assembly, installation, and test, first of the remote segment and then of the total system.

During Function H on the development cycle model, it may be necessary to retrofit some of the materials for maintaining operator and maintenance performance which are produced as the output of activity H-11. Retrofit may come about as a result of the testing which will occur during activities H-14 and H-16 wherein the personnel products are integrated and tested. This could at worst entail an analysis, redesign, and refabrication of those elements of the PMM which do not support man's reliability as required in the performance of selected functions. Since retrofit is costly both in development time and dollars, it is vital that all possible efforts be made, prior to personnel products package testing, to ensure with high confidence the prediction that the PMM will satisfactorily pass the tests within tolerance. Such efforts are provided by the technical management activities that oversee the PMM activities.

Resources Needed

There is no well-organized subdiscipline within human factors or biotechnology that is concerned specifically with all techniques for maintaining human performance. There is, however, an evolving concern with the development of techniques and data for predicting the reliability with which specific tasks will be accomplished by human performers. Techniques for evaluating proposed methods for maintaining human performance are virtually completely lacking. Nevertheless, what is required to implement the activities in this group are specialists in the fields of: (1) prediction of the reliability with which humans will perform specific assigned tasks, (2) specialists with a broad knowledge of the techniques that may be applied successfully to maintain human performance to achieve probability-of-success goals, and (3) specialists capable of evaluating techniques for maintaining human performance.

Activities E-6 and E-10 require basic data and techniques for estimating the reliability with which each function assigned to man will be performed by crew members unsupported by additive loops. In view of the first-order effects of operator (prime means) failure, good reliability estimates are required, and where data available in the literature are insufficient, it may be necessary to provide resources for applied experimentation to develop empirical bases for estimation. In activities F-5 and F-8, there is a similar requirement for the estimation of the reliability with which maintenance tasks may be expected to be carried out. In general, however, less precise estimations are required than in the case of operator performance. Because activities F-5 and F-8 require the identification of means by which human performance maintenance will be implemented, specialists with knowledge of what is available in the state of the art and of what is effective are required.

Activities G-9 and G-15 require that fabrication models for materials for use on the job be prepared. Assuming that means are properly called out in the output of F-5 and F-8, these activities require common engineering skills supported by knowledge of effects on human behavior of specific materials configurations.

It is activities H-9 and H-11 which create the most severe resources problem. The matter of fabricating materials in response to the models prepared in Function G does not cause the difficulty. Rather, it is the requirement that supporting data be provided to show that the fabricated materials do indeed provide for the added increment of reliability needed to meet target probability-of-output objectives. What is required to provide the supporting data are techniques for determining, within reasonable cost and time limits, whether or not the delivered materials will be effective over long periods of time in use on the job. Especially in the case of operator performance maintenance, reliability requirements may be very high and good estimates of the effectiveness of materials for maintaining operator performance may be very important indeed. Recognizing that the technology is deficient, the best that can be said here is that care must be taken to select the best qualified technologists available, and that provision will probably have to be made for equipment and test subjects to enable validation of the estimated effects of maintenance needs for human performance.

Identification of Additive Loops on Operator Performances
Activity E-6 (Remote)

The output of this activity identifies all of the additive provisions that are recommended for the purpose of ensuring that probability-of-output requirements for functions to be implemented by remote operator performance will be satisfied. Functional design of the additive loops on operator performance will be stabilized in the output of Function E. Therefore, supporting data will accompany recommendations for such additive loops in order to demonstrate that the functional designs can be implemented without forcing the system design out of its target cost, quality position.

The manner in which the supporting data are to be presented will be identified in the input to activity E-6. The input derives from E-3, a technical management activity.

Activity E-10 (Local)

The inputs and outputs of this activity are similar to those for E-6. E-10, however, is concerned with additive functions to support operator performance in the local segment. Therefore, its input will identify limitations, and the supporting data in the output must show that weight, power, volume, and crew size constraints are not violated by the recommendations.

Identification of Additive Loops on Maintenance Technician Performance
Activity F-5 (Remote)

This activity is concerned with the reliability of maintenance technician performance in the remote segment. It is thus concerned with second- and third-order additive loops. (It is unlikely that lower orders of additive loops will be employed for the purpose of providing for the reliability of maintenance technician performance.) The output of this activity must identify the functional design of additive loops for maintaining maintenance technician performance and the means for implementing those additive loops. Means may include requirements for personnel performance and hardware means. The input to activity F-5 derives from F-3, a technical management activity. That input will identify all previously stabilized relevant design decisions and will call out the manner in which the output of F-5 is to be evaluated.

Activity F-8 (Local)

Like the output of activity F-5, the output of F-8 must include functional design and means identification. The functional designs will be those required to provide for the maintenance of maintenance technician performance in the local segment. The output will include identified means for implementing all additive loops on human performance and supporting data as required in the order to F-8 from F-4, the technical management activity which precedes it. In general, F-5 and F-8 are similar. However, F-8 must respond within weight, power, volume, and crew size constraints identified in its input.

Preparation of Fabrication Models for Materials to Maintain Human Performance Activity G-9 (Remote)

The output of this activity includes all of the fabrication models required for the construction of materials for use on the job to maintain human performance in the remote segment. It thus encompasses materials necessary to maintain operator performance and those necessary to maintain maintenance technician performance. The input to this activity derives from the crew package technical management activity, G-5, which precedes it. That input will call out the manner in which the required fabrication models will be evaluated.

Activity G-14 (Local)

This activity is to the local segment what G-9 is to the remote segment. Its output is a set of fabrication models for material to maintain human performance in the local segment. Its inputs and outputs differ from those of G-9 in that G-14 must be carried out within the constraints imposed on the local segment.

Fabrication of Materials for
Maintaining Human Performance
Activity H-9 (Remote)

The output of this activity is an output of the development cycle; it is the fabricated materials necessary for maintaining operator and maintenance technician performance in the remote segment. The output must also include supporting data developed by evaluation of the materials to demonstrate that the requirements for them are satisfied. These data must thus demonstrate that the materials are capable of providing the increments of reliability necessary for the achievement of overall probability of success goals for functions assigned to operator and maintenance technician performance.

The input from this activity derives from activity H-5, a crew package technical management activity. The input is essentially an identification of the test by which the materials to be produced in H-9 will be evaluated. The input thus provides the basis for generating the supporting data needed in the output.

Activity H-11 (Local)

This activity is in the sequence of activities concerned with fabrication of the local segment. It is similar in its role to the role of H-9. The outputs differ principally in that the supporting data must show that evaluation has been carried out employing weight, power, volume, and crew size constraints as criteria. The constraints are identified in the input which derives from H-6, a crew package technical monitoring activity.

Discussion

The basic objective of Function E is to develop a stabilized functional design of the additive set jointly with a selection of stabilized means for the prime system. Activities E-6 and E-10 are therefore concerned primarily with identifying requirements for additive loops on operator performance so that decisions to implement prime functions by means of operator performance may be stabilized. Investigation of methods by which to implement additive loops on operator performance is necessary primarily to develop confidence that problems will not be encountered in designing and fabricating such means. Given assurance that the needed additive loops can be implemented within limits on the local and remote segments, it will be possible simultaneously to stabilize with confidence operator performance allocation and functional design of additive loops on operator performance.

The achievement of these objectives requires that the inputs to E-6 and E-10 identify the probability-of-output goals for each prime function. Within these activities it will then be necessary to estimate the reliability with which operator performance can be expected to implement each of the prime functions which might be allocated to performance by crew members. Whenever the estimates of reliability are less than the required probability of output, and whenever the estimates of reliability are based upon suspect data, additional work is necessary. Better data must be developed where needed to determine if there is a true gap between reliability and required probability of output, until finally there is identified a list of all the operator performances with which such gaps are associated. For each such operator performance, it will next be necessary functionally to identify an additive loop that will make up for the gap in reliability and then to determine means by which the additive loops may be implemented. In the case of activity E-10, means must be found within the weight, power, and volume budgets. Further, in activity E-10, care must be taken not to impose time requirements for implementation of maintenance functions on crew members such that there is interference with more important crew tasks. Wherever satisfactory means can be identified for implementing necessary additive loops on operator performance, implementation of the subject function by means of operator performance may seriously be considered. On the other hand, if means cannot be found within limitations that will close the reliability gap, then there is a clear implication that new means must be sought for implementing the prime function. Responsibility for such reassignment must be made at the level of technical management for segment development; it cannot be made within the personnel products activities.

The output of Function F is a stabilized means design for the additive set. Inasmuch as all provisions for maintaining operator and maintenance technician performance fall within the additive set, such means must be identified in activities F-5 and F-8. It is therefore required in F-5 and F-8 that estimates be made of the reliability with which each maintenance technician performance will be carried out. As in Function E, differences between requirements for probability-of-output and reliability estimates will generate requirements for maintenance and maintenance technician performance. In F-5 and F-8, design will be carried all the way through to the recommendation of means by which additive loops on human performance are to be implemented.

In developing estimates of the reliability with which each operator performance and each maintenance technician performance may be carried out, it will be necessary to make assumptions about the environmental conditions that will obtain in the operational situation. Therefore, data germane to those conditions must be provided as input data. Where the conditions can be expected to contribute to degradation of reliability, it will be necessary to call for correction of those conditions and thus to provide inputs to the development of the personnel support systems. It is the purpose of these support systems to provide environmental conditions consistent with the assumptions and demands of the activities concerned with the reliability with which tasks assigned to crew members will be carried out.

The means identified for implementing additive loops on human performance will typically include functions to be carried out by means of crew member performance and functions to be carried out by means of hardware. Where crew member performance is involved in additive loops, frequently it will be necessary to supplement the crew member performance with "hardware." Such supplementary hardware may include true hardware, such as simulators, but it may also include printed test materials, printed study materials, and other quasi-hardware.

It is in Function G that fabrication models for materials to maintain human performance are prepared. In Function F, there is an identification of the materials needed, but the detail of identification does not include the detail required to enable fabrication. Fabrication of the needed materials may encompass training for crew member implementation, and the fabrication of printed material and hardware. Therefore, in the case of the remote segment, activity G-9 may be expected to interact with activity G-10 which is concerned with preparing for the training of the crew. Furthermore, job aids may be employed to support tasks involved in maintaining human performance. If they are required, there must be interaction between activities G-8 and G-9 so that G-8 will produce the needed job aids.

In the preparation of means for maintaining human performance for the local segment, interaction is required between G-14 and G-15 to provide for job aids, and between G-14 and G-13 to provide for training crew members to implement their own additive loops on human performance. In the local segment, however, any materials required for the purpose of maintaining human performance must be selected carefully to fall within weight, power, and volume limits, and must be justified as a good use of weight, power, and volume. Yet further, requirements for crew members to implement monitoring and corrective and preventive activities for the purpose of maintaining human performance must be shown to fall within the time available for crew activities without interfering with other crew activities that have greater impact on system quality.

It is in Function H that the materials necessary for maintaining human performance are fabricated. These materials are delivered as end products of the development cycle and are installed as part of the operational system. They are not materials to be used within the course of the development cycle, except that it may be necessary to familiarize crew members with their use in H-8 and H-10, the activities concerned with crew training. Ordinarily, the fabrication of the simulators and test devices, and exercises required to provide for the maintenance of operator and maintenance technician performance will be relatively straightforward. As mentioned earlier, however, activities H-9 and H-11 must also develop data to demonstrate that the materials which they fabricate meet requirements for those materials. Essentially, those requirements will be stated in terms of increments of reliability to be added to the inherent reliability with which each operator and maintenance technician performance is carried out. It is, therefore, incumbent upon activities H-9 and H-11 to demonstrate that the delivered materials do indeed add the needed increments of reliability when they are employed in the prescribed manner by the selected and trained crew members. Frequently, the increment in reliability to be added may be rather small — especially in the case of operator performance, where high reliabilities are required. When the increment that is needed is small, and when its effect is to improve an inherent reliability that is already high, then the problems of demonstrating that the desired effect is required are severe indeed. Techniques for demonstrating within reasonable cost and time that the reliability with which a man performs a given task has been improved from, say, .95 to .99, have simply not been well developed. Nevertheless, the effect of failure to provide for the reliable implementation of system functions allocated to man has the same effect on overall probability of system success as failure to implement functions allocated to hardware with hardware of the required reliability. Therefore, attention to the task of demonstrating the effectiveness of additive loops on human performance cannot, in good conscience, be set aside.

VIII. DESIGN OF INTERFACES AND WORKSPACE TO PROVIDE FOR RELIABLE INTEGRATION OF OPERATOR PERFORMANCE

Activity Group Requirements and General Considerations

Whenever a system uses men to implement some functions and machines to implement others, there will be situations which demand interaction between man and machine. Thus, for example, when there is a flow of data from a man-implemented function to a hardware-implemented function, there will be a requirement for the output of the man to be received as an input by the hardware. Data flow requirements can also call for data to pass from machine to man. Unless deliberate attention is given to the proper articulation of means at such control and display interfaces, it is simply unlikely that every function output will be precisely the input that is required by the means which implements the follow-on function. Thus, unless someone worries about the problem of providing for "fit" between all system means to assure proper functional interfacing, it is simply unlikely that articulation will be perfect at every interface. Where articulation is imperfect and data fail to pass from one means to the next (that is, from one function to the next), then overall system probability of success suffers. In this chapter, we are concerned with the interfaces between operator performances and hardware. We include those interfaces which require that information pass from hardware to man with those interfaces which require that information pass from man to hardware. We will frequently speak about the former as a display interface and of the latter as a control interface. We are also concerned with man-man interfaces. Specifically, we must provide for activities in the system development process that will give attention to ensuring that there is not a degradation of system reliability which can be attributed to poor interfaces associated with greater performance. Chapter X deals with the interfaces between maintenance technician performance and hardware.

In general, to provide for proper fit at man-machine interfaces, one or both of two courses of action may be elected: (1) the capability of man to receive information or to transmit it may be changed by training, and (2) the form of the output of a machine may be modified by a special attachment so that man may receive it, or the kind of input that can be received by a machine may be modified by an input attachment to permit control behaviors that are within the capability of man.

Interface devices may be single-purpose or multipurpose, and they may be fixed or movable. Movable multipurpose devices are sometimes called tools. Design, for the purpose of achieving proper articulation at man-machine interfaces, is frequently called human engineering. This chapter is not "all about" human engineering, however, for the term commonly encompasses other development cycle activities which are outside of the scope of this chapter. It is for this reason that the chapter title does not employ the term human engineering.

Not only is this chapter concerned with individual interfaces between man and machine; it is also concerned with the set of all interfaces between a man who carries out assigned operator performances and the prime hardware with which he is involved. Thus, this chapter is concerned with workspace design as well as with design for man-machine and man-man interfaces taken separately.

Relationship of Activity Group to Development Cycle Model

The objective of this section is to identify, by reference to the development cycle model, the activities which comprise the activity group under consideration, and how they "fit" into the model, and the related efforts throughout the model including the true beginning and end of concern for interface problems.

There are two activities which form the activity group. These are E-8 (for the remote segment) and E-11 (for the local segment). The outputs of each of these activities are recommendations that are ultimately reflected in the design of the prime system means and in operator training. A data package is also delivered as an end product of the activity group. This package should contain information confirming that there will be no loss of system reliability due to failure of articulation at man-machine interfaces, and at man-man interfaces.

Activities E-3 and E-4 for the remote and local segments, respectively, provide to the activity group detailed descriptions of the operator performances to be carried out in the operational system, including reliability requirements and measures of outputs. A second major input derives from parallel prime system means design activities. E-7 and E-11 personnel should work with the prime system means designers to identify interface problems as they are generated.

The true origin of concern with man-machine interface problems in Phase II lies in activities D-4 and D-7. In these activities, decisions are made with respect to the prime system design, and recommendations are made with respect to which functions in the prime design man should perform. To obtain a prime system design that may be stabilized with confidence, there must be a thorough explanation of the personnel products problems that may be engendered by selection of the prime system design. Exploration must include attempts to identify likely man-machine and man-man interface problems and attempts to identify methods whereby these problems may be solved. The data generated in this "look ahead" will not be binding upon activities E-7 and E-11 as design guidance, but they will provide raw material that may be of use in carrying out these activities.

Inasmuch as human engineering decisions frequently require that assumptions be made about the physical and mental health and stature, age, and other attributes of crew members, it will be necessary for activities E-3 and E-4 to provide working assumptions.

Implementation of the design recommendations produced by E-7 and E-11 will occur in Function G where fabrication models for hardware will reflect interface solutions which require hardware adjustments. Interface solutions involving training will be implemented in G-10, and in G-14, where training materials are prepared.

Interim evaluation of proposed solutions for interface problems will be carried out in Function E at the personnel products level, at the segment level, and at the system level (activities E-13 through E-17). Final evaluation, and therefore the final opportunity for retrofit before delivery of the complete operational system, will take place in Function H, first at the crew package level, then successively at the personnel products level, the segment level, and the system level (activities H-13 through H-20). The objective of the evaluations in Function H will be to demonstrate that there is no loss of reliability which can be attributed to failure of articulation at man-machine and at man-man interfaces. Thus, the overall criterion will be a reliability criterion.

Resources Needed

Although the activities described in this chapter do not encompass all of human engineering, nevertheless, basically they require the application of the human engineering discipline. This disicipline is so well documented that it would be quite inappropriate to attempt here to characterize it in a few words. However, to provide guidance for estimating the nature and size of the commitment required to carry out the activities in this group, we will briefly call attention to the major characteristics of the resources needed.

Both of the activities in this group can be carried out adequately by human engineers trained in control and display design and workspace layout. Concern for maintenance technician interfaces is not included in these activities, therefore the human engineering skills associated with "maintainability" are not required. The human engineers assigned to carry out these activities should be supported by a comprehensive human engineering data pool (access to an appropriate library might serve this purpose). To provide a more certain basis for the comprehensive identification of all interface problems and to provide a vehicle for the evaluation of proposed solutions to identify interface design problems, it will be necessary to build mock-ups and to test human subjects.

Design of Operator Interfaces and Workspace
Activity E-7 (Remote)

The output of this activity is a set of recommendations for the solution of man-machine interface problems. The output will include, for example, suggested designs for interface hardware, suggested designs for workspace layout, and recommendations with respect to operator training for the purpose of solving interface problems. Recommendations will be for operator performance interfaces in the remote segment.

The input to activity E-7 derives from E-3, a personnel products technical management activity. The input identifies the manner in which the solutions recommended in the output of E-7 will be evaluated, and will thus provide a basis for the development of the supporting data required in the output of E-7, as in the case of every other design activity.

Activity E-11 (Local)

The output of this activity is concerned with operator interfaces in the local segment. It will identify the manner in which crew performance of operator functions is to be articulated with the hardware in the local segment. Solutions may include recommendations for special hardware interface devices, recommendations for special operator training, and workspace layouts.

The input to E-11 derives from E-4. The input is in the form of a requirement statement which identifies the procedure for testing the output of E-11. The output of E-11 will therefore include supporting data developed by testing to demonstrate that the recommendations are satisfactory. Inasmuch as E-11 is concerned with the local segment, the supporting data must show that recommendations fall within constraints identified in the input.

Discussion

The outputs required of either activity in this group may be encompassed by four classifications: (1) recommendations for hardware design actions that will achieve the desired articulation at specific individual man-machine interfaces; (2) recommendations that specific capabilities be taught crew members in order to achieve the required articulation at man-machine and at man-man interfaces; (3) recommendations with respect to the overall layout of the environment in which operator performance is carried out by a crew member in order that the interface problems associated with all interfaces taken together may be solved; and (4) data which demonstrate that adoption of the recommendations will result in system performance to the end that no degradation of reliability can be attributed to failure of functional articulation at man-man and at man-machine interfaces. It will be a goal of each activity that these outputs be produced within the resources allocated for the purpose. A typical method for implementing either of the activities in this group has been chosen for discussion here as a vehicle for setting forth some of the factors to be considered in planning for these activities. The method chosen is encompassed by four major steps. In overview, these steps are as follows: the first step is focused upon determining what interfaces require attention. In many cases in the normal course of design, interface problems will be recognized and solved without specific attention by human engineering personnel. The objective of the second step is to determine alternative ways in which identified interface problems may be resolved. Alternative interface "adapter" devices and training solutions may be recommended. The third step in the method identifies the solutions of choice. Such solutions must fall within constraints set forth in the "order" or requirement for the activities. Where solutions cannot be found within weight constraints, for example, or within the capabilities of the types of personnel who man the crew, the unsolvable interfaces must be identified to technical management so that alternative ways of structuring the system may be found. The selection of solutions must be within an acceptable concept of the workspace. In the final step, an overall workspace and attendant solutions to individual interface problems within the workspace will be prepared. These recommendations will be the major output of the activity; they will be accompanied by data to support the contention that they will solve interface problems within identified constraints.

The paragraphs below treat each of these four steps within a typical activity in more detail. The intent here is not to advocate a method, but simply to use a representative method discussion as a basis for identifying the nature of the activities in this group.

Step 1

The determination of the specific interfaces requiring human engineering attention requires that all of the man-machine and man-man interfaces first be identified. The proper basis for identification is a functional description of the system which indicates the functions to be implemented by hardware means and those to be implemented by human means. The functional description of the system required or needed for this purpose must be so detailed that all interfaces can be identified. If it is not available from the data pool of the system development cycle, then it may be necessary to prepare it within this work step. As recommendations for prime hardware are developed in Function E, it will be possible, by following the data flow, to determine the interfaces associated with each hardware package, and to determine the criteria for proper articulation of man and machine at these interfaces. By the use of the function description it will be possible to determine when all interfaces of interest have been comprehended. In many cases, initial hardware selection plans will create interfaces that are manageable without human engineering intervention. These may be set aside for reconsideration when workspace layout is considered. The remaining interfaces must be tagged for further action in work step 2.

In order to identify interfaces that may give rise to problems, it will be necessary to appeal to basic data which describe the capabilities of man to receive data and to transmit — that is to control. Time must be considered as a factor in these analyses as well as the nature of the inputs and outputs from and to man. Specific information about the characteristics of the intended crew members must also be taken into account jointly with the basic data about population characteristics. In these analyses, a discovery of an interface at which there will be unreliable articulation does not necessarily mean that a problem has been identified. The determination of whether or not there is a problem requires consideration of the criteria for assessing the output of the receiving function and specific requirements for the probability of success of the functions involved. It can be said that there is a problem only when the expected reliability of output of the receiving function will be degraded below that required because of unreliability at the interface in question, or because of second-order effects on performance which may be attributed to the manner in which the interface is implemented.

Step 2

To determine alternative ways in which interface problems may be solved requires a good method of access to the extensive human engineering literature which identifies solutions that have been developed and used in the past. What is required in this work step is to identify sufficient alternatives to provide a basis for an integrated solution of the set of interface problems associated with the operator performance of a crew member in the workspace layout to be considered in the following step. Frequently, the solution to problems of articulation is found in the use of "adapter" devices which are fastened to prime system hardware and which transduce prime system hardware outputs to a form that is reliably employed as an input to operator performance. Other adapters accept the kind of control outputs of which man is capable and transduce them to inputs that prime system hardware can employ. However, the kinds of solutions available to the human engineer are not exhausted by the extensive lists of typical adapter devices described in the human engineering literature. The human engineer may opt to train crew members who will carry out operator performances to employ the outputs of prime hardware without modification of these outputs by special devices. Such an option is possible, of course, only when the prime hardware output can be sensed and sufficiently resolved by the natural receptors of humans. The augmentation of reception by means of portable devices, such as portable optical devices, is considered a special case of the adapter type of solution. The human engineer may also elect to employ job aids to assist in the resolution of certain man-machine and man-man interface problems. Thus, in lieu of training, a faceplate beside a display may provide all of the guidance that is necessary to enable its reliable use by crew members.

Step 3

The selection of the methods by which identified interface problems will be solved must include consideration of several intersecting sets of constraints and limitations. The required reliabilities must be achieved not only when the solutions are taken separately, but also when they are taken together. Thus, two solutions which are adequate when separate may cause conflict when they are used side by side. The set of solutions selected must admit integration into an overall workspace arrangement which contains all of the interface solutions and provides for the articulation of the crew member with the interfaces related to his operator performance. Thus, the relationship of the crew member to his interfaces as a whole must be considered as well as the interfaces separately. When considered as a whole, the set of solutions must fit into the space available for them without loss of effectiveness. Frequency of use, time conflicts, as well as position conflicts must be taken into account. The set of solutions for the local segment must lie within weight, power, and volume limits set forth in specifications prepared by technical management. The reliability of adapter devices themselves must be taken into account, and so must cost. Given this complexity, Step 3 ordinarily will involve many trade-offs before a satisfactory package of interface solutions can be achieved. Inasmuch as it may be necessary to stabilize some solutions prior to others, it may be necessary sequentially to seek a solution of the total interface package.

Step 4

In this step, the recommended workspace layout for operator performance must be described. The description must include specific identification of the manner in which each individual interface problem must be solved. Recommendations with respect to interface problems to be solved by means of training must be detailed, and recommendations for job-aid solutions must also be prescribed. It must be demonstrated that all man-machine and man-man interface problems have been considered, and that solutions have been proposed in every case in which a need was found for intervention. Should it not be possible to show that all problems have been solved, unsolved problems should specifically be identified, the reason for failure to solve the problem should be identified, and recommendations for an approach to solution should be stated. These recommendations will constitute the principal output of the activity and will be the basis for integration with other recommendations in Function E at the personnel products, at the segment, and at the system level.

The output of this final step must also include supporting data. The data must demonstrate that the solutions are compatible with parallel recommendations for hardware implementation of system functions, and with recommendations for implementation of prime function by means of operator performance. The data must also provide a basis for confidence that acceptance of the recommendations will result in a system in which no loss of reliability over and above expected losses will be attributable to failure of articulation at man-man and man-machine interfaces. Finally, the data must demonstrate that the recommendations will not lead to second- and third-order problems of system development later in the development cycle. Any problems which may be engendered by the recommendations must be identified along with proposals for their solution.

IX. DEVELOPMENT OF THE PERSONNEL SUPPORT SYSTEMS

Activity Group Requirements and General Considerations

The reliability with which a man will implement an assigned function will be affected by the conditions under which he is required to perform. Thus, reliability may be degraded if environmental conditions are unfavorable. What is required in the case of man, as in the case of hardware, is provision for sustaining those environmental conditions necessary for the required reliability of performance to be realized in system operation. Here we will call a system which provides such conditions a personnel support system.

In aerospace systems, personnel support systems are needed: (1) to sustain personnel psychologically and physiologically so that they may perform their assigned functions with the required reliability, and (2) to preserve the long-term mental and physical health of system personnel within limits accepted by society. The first need is of primary importance from the point of view of system objectives, for it relates directly to the probability of mission success. The second derives from the "adjacent" social system, and is of secondary importance from the point of view of mission objectives. That is, the second need exists only when the first exists.

In an aerospace system, there must be a personnel support system for each segment if both segments are manned. The personnel support system for the local segment will be referred to here as the Human Support System. Roughly speaking, the Human Support System encompasses the concepts of an environmental control system, a life support system, and all provisions for habitability. In most systems, reliability of operator and maintenance technician performance may be said to be the sole objective of the Human Support System, for the requirements placed upon the system to achieve these objectives will usually be more stringent than the requirements placed upon the Human Support System for the purpose of preserving human life and sanity. An exception to this general observation is the case in which provision must be made to preserve human life after system failure has occurred. Abort provisions clearly cannot be justified as accounting for system probability of success.

The personnel support system in the remote segment is referred to here as the Safety and Support System. As in the case of the Human Support System, a primary objective of the Safety and Support System is to provide for reliable human performance; thus, it must provide conditions such that no loss of reliability of human performance can be attributed to improperly controlled external environment. In this sense, the Safety and Support System encompasses air conditioning, occupational medicine, and occupational psychiatry, for examples. Typically, in the case of an aerospace system, the Safety and Support System must also provide for an acceptable interface between the aerospace system and adjacent systems where the safety of personnel in adjacent systems is in danger.

The Human Support System may require a significant share of the weight, power, and volume allocations in the local segment of an aerospace system, and the need for an HSS is therefore of great importance in determining whether or not man will be included in the local segment. Because the nature of these two personnel support systems is so different, they will be discussed separately in this chapter.

Relationships of the Activity Group to the Development Cycle Model

In this section attention is focused upon describing the development of the Human Support System and the Safety and Support System within the framework of the development cycle model. This is accomplished in two parts. The first part traces on the model the evolution of the personnel support systems. The second part provides an introduction to the types of difficulties which would necessitate retrofit. Since the HSS and the SSS are in many ways different, each support system is treated separately in the following discussion.

The Human Support System

HSS Evolution

Human Support System development starts in Phase II in activity D-7. Here representative design efforts are carried to the point where confident predictions can be made that HSS development is feasible and that it will not drive the system out of the desired cost, quality position. Inasmuch as a prime objective of D-7 is to establish a basis for selecting the size of the crew for the local segment, Human Support System expense in terms of weight, power, and volume for alternative crew sizes must be studied. By the end of Function D, crew size will have been selected and with it a weight, power, and volume budget for the Human Support System.

The functional design of the prime system is accomplished in Function D. The prime system does not include the Human Support System, however; consideration of its prime functional design must wait upon crew size stabilization. Therefore, when the functional design of the prime Human Support System is generated in Function E, design lags by one phase behind that of the prime system. In order that design might catch up with the prime system, the activity in Function E (E-12) that is concerned with Human Support System design is charged with accomplishing both a functional design and a prime means design. By this method, design of the Human Support System is accelerated so that requirements for operator and maintenance technician performance in the HSS itself may be fed to other activities concerned with man performance in a timely manner. In Function F (activity F-10) the additive set for the HSS is designed, bringing the development process for this support system to the point which permits fabrication models to be developed in Function G (activity G-16) in parallel with the development of other fabrication models for the system. The fabrication function is Function H; the Human Support System is fabricated in activity H-12.

Of the three activities uniquely concerned with the design and fabrication of the Human Support System (E-12, G-16, and H-12), we will discuss only E-12 in detail in this chapter. Activities G-16 and H-12 are primarily hardware design and fabrication activities. They are unique hardware activities in that they are carried out in response to human factors requirements and should thus not be confused with prime system hardware activities. Nevertheless, as hardware engineering activities they fall outside of the scope of the present essay.

Activities E-12 and F-10 (see Chapter VI) develop requirements for personnel selection, requirements for operator and maintenance technician performance to be obtained by training and job aids, and requirements for materials to maintain reliability of human performances on the job. Such requirements, as they are generated, must be fed to the appropriate man-related activities identified in the model. Because the design of the Human Support System is initiated somewhat belatedly, some of these requirements will have to be fed to parallel personnel products activities. What remains for activity H-12 after such requirements are sent out is a requirement for fabrication of the hardware.

Retrofit Needs

The second area of concern is the adjustment of the HSS by means of retrofit activities. Some of the major reasons for having to perform a retrofit are:

1. Hardware Packaging. — When the hardware is finally put together, packaging incompatibilities may be discovered which do not permit adequate performance by man or by hardware.

2. New Technology. — During the course of system development, new processes or equipment may become available which were not anticipated but which are better for the purpose, with respect to reliability, dollar cost, weight, power, or volume.

3. Unanticipated Sources of Error. — Regardless of how well system planning and design are accomplished, the real test of the system during the development cycle is when it is entirely integrated and

tested against the performance requirements established early in the development process. During tests, some equipment or procedure may yield an out-of-tolerance situation. It may not be possible to anticipate, for instance, all the environmental variables and their effects on system operation. For this reason, changes in equipment may have to occur as a result of system testing.

Retrofit problems specific to the HSS equipment would occur during the "late" development activities. There are several primary "test points" where HSS equipment could be found to be inadequate for one reason or another: H-12, H-16, H-18, or H-20. Activity H-12 actually produces the equipment in its final form. The testing required in H-12 may well reveal problems. In H-16 other problems may be discovered when trained personnel are brought together with the HSS equipment. In H-18, the HSS means in toto (i.e., equipment, people, job aids) may not function adequately with the prime hardware. Retrofitting at this point may turn out to be more costly and time consuming than earlier retrofitting.

The last effort during the system development process where the HSS could be found to be inadequate and require retrofitting would be during activity H-20. This activity is involved with testing the entire system (including both the remote and local segments) for required performance capability. A retrofit of a part of the HSS at this point could be extremely costly.

Because of the increasing cost of retrofitting as the development process progresses through to H-20, the care with which the elements of the HSS are fabricated and tested early in Function H cannot be overemphasized. While the discussion has surrounded the HSS equipment with respect to retrofit problems, failure could occur on the part of personnel trained in HSS functions or in the job aids subset produced specifically for the operation and maintenance of the HSS.

The Safety and Support System

SSS Evolution

An aerospace system is likely to present hazards not only to its ground crew, but also to other personnel in the environment of the remote segment. In fact, some systems may have potential adverse affects on agriculture and industry in the environment of the remote base as well as upon people. Therefore, concern with the Safety and Support System of the remote segment begins very early in the devélopment cycle. Even before Phase II is initiated, there must be concern in Function C with the possible effects of alternative system solutions on their environments. This concern will culminate in the adoption of an "A" score formula by which the good and bad effects of the system on its environment will be measured. A tentative "A" score formula will be included in the Basic System Specification which is in the output of Function C and initiates Phase II. Those facets of the "A" score formula which deal with biological effects are a primary concern of the Safety and Support System. Thus, the Safety and Support System is concerned with sustaining conditions within the remote segment for the benefit of the remote crew members and without the remote segment for the benefit of adjacent systems in the environment of the remote segment.

As in the case of the Human Support System, the Safety and Support System is anticipated in Function D (activity D-4). However, there is no attempt to stabilize any aspect of the design of the Safety and Support System until its functional design and prime means are considered in activity E-8. Activity E-8 is discussed in this chapter. In activity F-7, the additive set for the SSS is designed. This activity is discussed in Chapter VI. Fabrication models and tools for the Safety and Support System are developed in activity G-7, but fabrication is carried out in activity H-7. Both of these activities are concerned primarily with the development of fabrication models and with the fabrication of hardware, and they are not discussed here in detail. As in the case of the Human Support System, requirements for operation and maintenance of the Safety and Support System are fed to appropriate activities in the line of development for the remote segment as they are generated. The first integration and test of a complete Safety and Support System is undertaken in activity H-16, where the trained crew and the Safety and Support System are joined.

Retrofit Needs

The amount and variety of SSS means may be far greater than what will be generated for the local system. This would certainly be the case in a manned space venture, for which the SSS equipment might be distributed across the face of the earth. The chances for error in the development of SSS means may, in such a case, be much more numerous than for the HSS means. Therefore retrofit problems may be more widespread for the SSS than the HSS.

The term retrofit as used here refers only to corrective actions on development cycle end-product items. The end products which are related to the SSS consist of the SSS personnel, their job aids, their performance maintenance materials, and the SSS hardware.

Looking at the system development model once more, it can be seen that the appropriate function during which retrofit would occur is H.

The first point in the development of the SSS where major needs for hardware retrofit may become apparent is activity H-15. At this time, typical personnel trained in SSS functions and their associated materials would be brought together with the SSS equipment and tested as a unit. The SSS equipment tested for performance during H-7 would bring with it data on test results to H-15. Similarly, the personnel trained in SSS functions would have been carried to a required level of performance on such tasks. Likewise the job aids and performance maintenance materials would have been validated at this point. When everything is brought together, however, it may be anticipated that retrofit needs will be uncovered.

A bigger test of the SSS ability to provide proper support to remote segment personnel occurs in activity H-17 where the entire remote segment is tested as a unit. During this activity, the system personnel who perform operator and maintenance functions on system hardware must be supported by the SSS so that their performance remains within tolerance. Such a test of the remote segment would show the effects of bringing together, in a simulated operational situation, the complete remote segment. After this testing the maximum retrofit effort would probably be initiated because of the great variety of things coming together, resulting in more chances for errors to be found. It is therefore necessary, during the earlier H activities, that considerable pains be taken to coordinate efforts between parallel activities in order to minimize the likelihood of retrofit after H-17.

Resources Needed

Inasmuch as this activity group does not include activities concerned with hardware engineering aspects of personnel support system design and fabrication, we will not here identify the engineering talent and facilities needed for the purpose of preparing fabrication models or for the purpose of fabrication.

In the case of the Safety and Support System, what is required for activity E-8 is basically scientific and engineering talent. To account for the design of a system that will secure the well-being of crew members and of adjacent populations, specialists are required who can identify potential hazards and associate them with specific unwanted biological effects. Specialists who are familiar with the state of the art of personnel system means are also needed to identify potential solutions to the problems called out by the former group of specialists. The latter group will include engineering talent specialized in hardware and procedures necessary to implement a comprehensive support system for the remote segment. In order to identify hazards and to support the engineering group with design suggestions, it will ordinarily be necessary to employ specialists in industrial hygiene, occupational medicine, psychology, safety, and related subdisciplines. Ordinarily, it will not be necessary to provide mock-ups and prototype equipment in support of activity E-8. Recommendations will be based primarily on design review and survey.

The resources needed to implement activity E-12, which is focused on design of the Human Support System, are somewhat different. Specialist talent in the fields of space medicine, human factors, physiology, toxicology, and related disciplines will be needed to identify Human Support System requirements. These specialists must be supported by an extensive data pool to which they have ready access. The engineering talent required to accomplish a prime system design must be specialists in environmental control and life support system development, and must have access to laboratory and fabrication facilities so that applied engineering experimentation may be carried out as needed. Extensive tryout may be required even in the early stages of Human Support System design because of the need to design within tight weight, power, and volume budgets, and because of the requirement for very high reliability of Human Support System operation. Without access to logistic support from the outside, the accomplishment of high reliability operation requires empirical testing.

In view of the important role that is played by anticipatory Human Support System design in activity D-7, it would be reasonable to expect that the core of the specialist group for activity E-12 would work in activity D-7 to assist in estimating the Human Support System necessary for each size of crew considered.

Functional Design and Prime Means Design of the Safety and Support System Activity E-8 (Remote)

The output of this activity includes both a functional design and a means design identifying the prime hardware needed to implement the Safety and Support System. Data must also be provided to show that the recommended Safety and Support System will satisfy its requirements and that it can be fabricated and operated within cost allocation. The input derives from E-3. It is a requirement statement for the Safety and Support System which identifies the manner in which the design will be evaluated.

Functional Design and Prime Means Design of the Human Support System Activity E-12 (Local)

A functional design for the Human Support System and a prime means design are both included in the output of this activity. To support the recommendation that the designs be employed, data are also required which demonstrate that the Human Support System will provide conditions under which expected reliability of human performances will be seen in the local segment. Data are also needed to show that adequate local crew safety provisions can be made to safeguard crew members in case of mission abort and that long-term crew health and soundness of mind will not be impaired. Supporting data must also demonstrate that the Human Support System can be fabricated within weight, power, and volume constraints, and that its time demands upon the crew will not degrade overall system quality. The input to E-11 derives from E-4. It identifies the constraints within which the Human Support System must be designed and the manner in which it will be evaluated. It also identifies the crew size.

Discussion

Safety and Support System

This section describes a representative set of steps for producing the functional and means design of the SSS. The support of remote segment personnel is quite different than the support of local segment personnel. First of all, the Human Support System is in use only while the local segment is carrying out the flight part of the mission. Secondly, the local crew's size and physical placement are well fixed. Neither of these facts necessarily holds for the remote segment. For instance, the SSS means in the operational situation must support personnel on the ground not only during the time in which the local segment is "upstairs," but also during preflight and postflight phases. The remote segment, at least for a manned space mission, could occupy several geographic sites, each of which would have personnel on-site. Changes in manpower availability, fluctuations in the economy, variations in workload, and other factors would vary the crew complement within the remote segment during its planned life. In addition, the remote segment would probably have many more adjacent systems to interface with than the local segment. The dynamics of interfacing with the adjacent systems (e.g., the "local community," other aerospace remote-segment means personnel, etc.) would be much greater, since fewer constraints on making operating changes would exist than for the local segment. The "A" score derived early in system development (Function C in the development cycle model) would define the measure of interactions with adjacent systems.

In the past, remote segments have grown to support each local segment as they are developed. At most remote segment sites, facilities have been accumulated which are shared among the personnel of several different remote segments. The practice of occupational medicine, as one example function of an SSS, is often provided as a service to personnel associated with several remote segments. Such "sharing" is a practical and economical way to maintain the health of site personnel for all systems served.

For purposes of completeness, this section is guided by the assumption that the remote segment is built on "vacant" property. This initially forces attention to SSS requirements, and allows that portion of the design method devoted to means selection to consider those facilities which <u>are</u> <u>really</u> present purely as <u>alternative</u> state-of-the-art means (and not as constraints). This approach provides the designer with the freedom he needs to be objective and creative.

In what follows, we will present the essence of an approach by which activity E-8 might be implemented. Our purpose is not to advocate an approach but merely to use a stepwise discussion of the activity as a vehicle for characterizing it. Activity E-8 will be partitioned into eight sequential tasks (see Figure 10).

<u>Task 1. Define natural environment</u>. — The objective of this task is to identify for each remote site the environment to which remote segment personnel might be exposed during the life of the operational system if no SSS

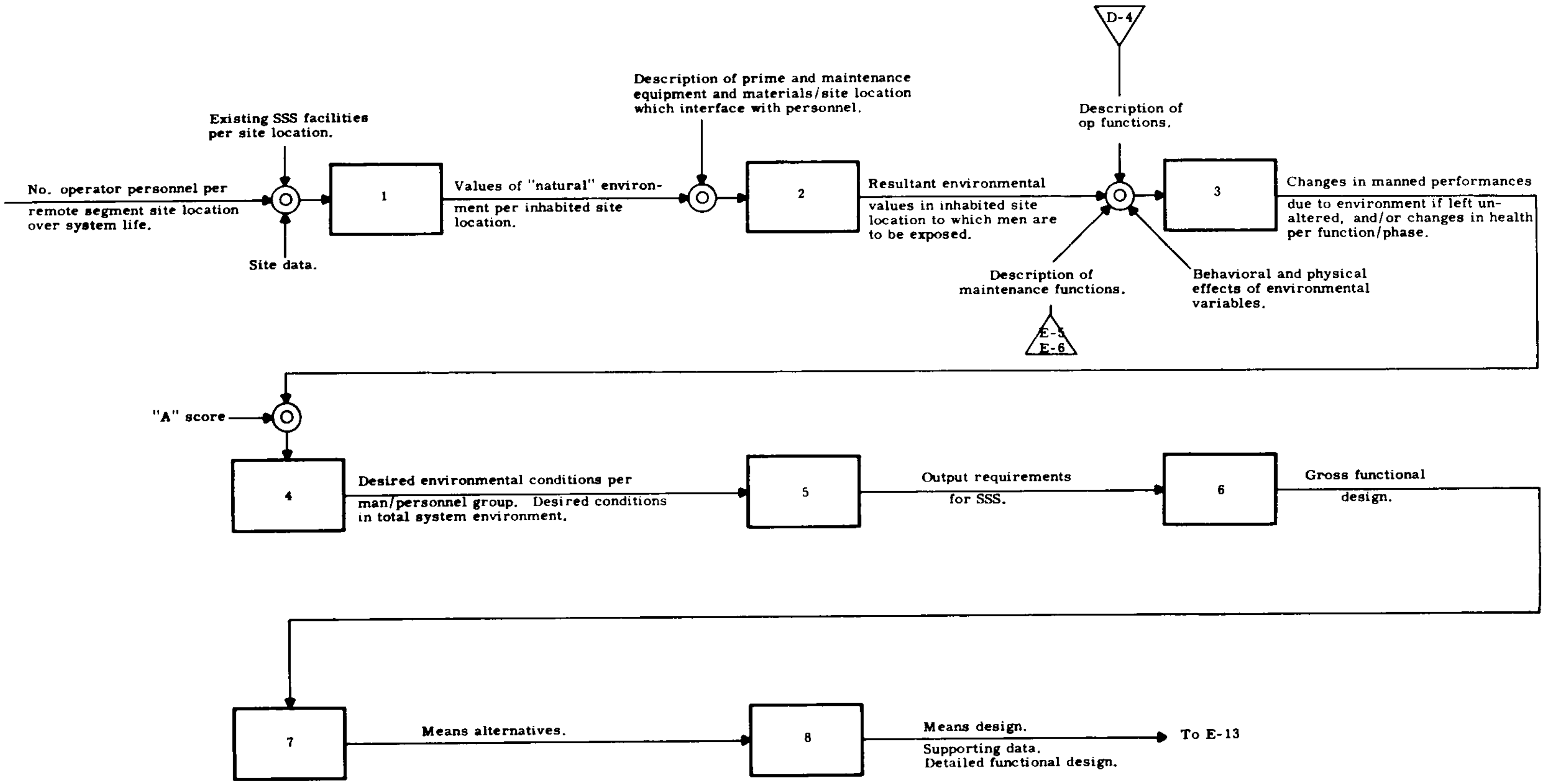

Figure 10. Major steps in SSS functional and means design.

were provided. One component is the weather. What would be needed would be the general weather conditions per site, and for launch sites, the distribution of weather conditions (micrometeorological) within each site (if the topology and size of the site produces heterogeneous conditions).

Other data inputs will include distribution of inhabitants in the surrounding area, data with respect to industrial installations and agriculture, and so on, such that adjacent systems which might be affected by operations at the remote site would be identified.

Even though this method strives to create an SSS for a remote segment which has yet to be built, it is usually true that some facilities have been constructed earlier at some of the remote segment sites, albeit for other reasons. These facilities typically contain SSS equipment (e.g., an air-conditioning system within a building) for personnel support. The environmental values (i.e., the actual capability of the SSS means <u>already present</u> as described by their output) then become <u>part</u> of the "natural" environment present at the site and must be described in the output of Task 1.

<u>Task 2. Combine present with operational environment</u>. — The objective of Task 2 is to determine the problems at each site when operationally created and natural environments are integrated. When this is done, the total environment which would impinge upon site personnel assigned to the performance of system functions will be known and factors affecting adjacent systems will be identified.

The term "operationally-created environment" as used here means essentially the environmental conditions engendered by the operation and/or presence of remote segment (and local segment during the pre- and postflight periods) prime system equipment and facilities. For instance, environmental conditions produced by the operation of some equipment might result in toxic vapors entering the atmosphere, increased temperature, vibrations, etc.

The input data which describe the operation of remote segment means would be provided by the prime system means design activities which occur in parallel with activity E-8. In addition, activity E-5 (recommended maintenance functions) people would be asked to "look ahead" in the development cycle to identify, for E-8 personnel, the maintenance equipment estimated to be needed per site.

Examples of the output of Task 2 are presented in Table 1. This output matches each inhabited site location with the environment which would obtain therein and relates the effects of combining natural with operationally-created environments. Column 1 on Table 1 contains examples of such combining.

Task 3. Identify threats to performance and health. — The goal of Task 3 is to determine the extent to which man's performance and/or health would be changed due to the combined environments and hazards associated with proposed remote segment design if nothing were done to alter the environments.

Since performance is the main concern, we wish first to isolate exactly what performances are expected per individual per remote site location over the life of the system. Task 2 provides input data on number of personnel per site location and the values of the resultant environment to which they would be exposed. Descriptions of operator performances per individual plus data on how "good" (i.e., reliability, accuracy, timing) they should be are obtainable from the end products of activity D-4, the originating source. Interaction with the personnel implementing activities E-5 and E-6 would yield similar performance descriptions on maintenance functions on prime hardware and operator performance, respectively. Since the SSS would be responsible for sustaining all remote personnel, regardless of where they are or what they do, it is necessary to obtain the same information on people who would do second-order and beyond maintenance efforts. These include functions to maintain the performance of maintenance people and maintain maintenance equipment. These two types of functions are not determined until activities F-5 and F-7, respectively — removed in time from the need for the output of E-8.

To obtain descriptions of second-order maintenance functions, E-5 and E-6 personnel would be required to "look ahead" to anticipate what the maintenance personnel would be doing, how many there would be, and where per

TABLE 1. INPUTS AND OUTPUTS FOR ACTIVITY E-8 DISCUSSION

(1) Environmental Factors at Specific Site Locations	(2) Function	(3) Physiological and Psychological Effects — "Health"	(4) Effects on Function	(5) Desired Environment	(6) SSS Output Requirements	(7) Means Design
I. Heat (Convective & Radiant); 125° F dry bulb; relative humidity 60%, surface temp. 200-300° F.	A. Radar Tracking	Liquid loss, inattention, general malaise.	Low degree of output, possible failure.	68° F dry bulb, 50% RH	Remove 15,000 Btuh and 6 lbs H_2O/hr.	Air conditioner and ventilation plus shielding of radiant sources.
	B. Electronics Maint. (sporadic)	Transient discomfort.	None	As above if feasible.	As above	As above
	C. Voice Commun.	Minor skin burns, apprehension.	Occasional errors — covered by backup.	Surface temp. less than 100° F.	Sources shielded and insulated.	Cooling coils, nonconductive coverings, gloves, training program.
II. Open sources of large amounts of electrical energy.	D. Installation of Launch Control System.	Death, unconsciousness, severe electrical burns.	Possible complete abort and/or delay.	Complete inaccessibility.	Sources shielded. No direct contact by man.	Electrical insulators, protective clothing & training program.
	E. Mission equipment test supervision.	As above — no burns.	Little chance of contact. Probability of effect slight.	Same as above.	Sources shielded. No direct contact by man when "hot."	As above, but less need for training program & protective clothing.
	B. Electrical Maint. (sporadic)	Same as for D above.	Backup available — little effect on function.	None — accessibility necessary.	No contact by man when "hot."	Safety program and protective gear.
III. Atmospheric contamination by HF/F; 0.01—0.5 ppm, up to 8 hrs/day; 0.01—300 ppm in acute episodes; liquid F also present up to thousand gallon quantities.	F. Fuel transfer.	Chemical burns, lung damage, extreme discomfort, death.	Mission abort possible.	F/HF atmospheric concentrations less than .01 ppm; no contact with liquid F.	Remove or contain (virtually all of) both liquid and gaseous F/HF.	The scrubbers (e.g., charcoal) on all exhaust vents, deluge systems, F resistant lines and fittings, strict safety procedures. Physical exams (pre-employment and every 6 months). Complete monitoring and alarm system at all points where relief may occur.
	G. Fuel check-out in vehicle.	As above, except for burn possibility.	Same as above but mission delay a more probable effect.			
	H. Maint. of Transfer System.	As above — severe problems less likely.	Some delay possible but backup available.	Need for change improbable except for "Health" reasons and general avoidance of concern. The likely desired atmosphere would be the same as above.	Same as above but only major system losses (1 gallon per day) need control.	Same as above but less emphasis on removal, more on containment of large amounts. Physical exams (pre-employment and yearly), general area monitoring and alarm systems, education program.
	D. As above (II).	As above.	Same as above but no backup.			
	E. As above (II).	As above, but low-level exposures probable.	Little or no delay problem.			

site they would be located. They would be required to do this anyway, since they must generate "supporting data" as an output (i.e., data provided as evidence that the maintenance functions defined are those truly needed to sustain the needed system reliability).

In order to produce the desired output, another input is required. This is an exhaustive body of data on the behavioral and physiological effects on man from environmental variables over the range of values expected in the remote segment site locations.

Given the descriptions of manned functions, the effects of environmental stressors and the actual environment to which man or contiguous groups of men will be exposed, the major effort in Task 3 would be to predict which performances by what personnel may be driven out of tolerance by the environment. Further, the effects upon man's immediate and long-term mental and physical health should be anticipated and documented. Being able to predict effects on performance may be difficult (at best), since little work has been done which relates environmental stressors to human performance. The bulk of extant data emphasizes physiological effects. To the extent that this remains true, rules for inferring performance changes from such information would necessarily have to be derived and applied to those personnel who would or could be under stress. This problem may warrant considerable research during Task 3. If research is done, it should be carried out so that sustaining operator performances receive top priority over maintenance performances. That is, if cost and time become critical, the accent on sustentation of man for carrying out maintenance efforts should ordinarily give way to operator performances.

The output of Task 3 would be a description of the suspected/known changes in man performances which would be out-of-tolerance in terms of required accuracy, reliability, and timing. Hopefully, the elements of behavior to be affected would be identified to provide specific criteria for SSS design. These elements of behavior should be coupled with psychological and physiological changes which would either cause or be associated with the behavioral changes.

Task 4. Determine desired environmental conditions. — Given the expected deleterious performance and health changes, this task would involve determining the desirable (changed) environmental conditions for man which would not yield these unwanted effects. There are also other SSS considerations not environment-specific to be accounted for. For instance, man must sleep, eat, drink, get rid of waste products, have free time, etc. All these are within the responsibility of the SSS and help to maintain personnel to a needed level of physical and mental health. Therefore, desired values for these parameters would also be produced during Task 4.

Based upon the literature, environmental needs for personnel should be specified for those functions which would be out-of-tolerance if the environment were unaltered. These needs are exemplified by column 5 entries on Table 1.

Several difficulties arise when attempting to impose a performance criterion on environment selection rather than a health criterion per se. The theoretical concept of supporting performance is not difficult to grasp or to justify, but implementing this concept is very difficult to do. It is problematic for several reasons. First of all, there is a lack of data which specifically relate health to performance. Secondly, those data which exist may very often be applicable to both health and performance. However, unless performance is used as a measure, it is difficult to conclude this. Thirdly, when utilizing a double criterion of performance and health, one runs into cases in which the person's immediate health is affected by environmental or working conditions but not his long-term health. Conversely, one can think of examples in which a person's immediate health is not threatened but his long-term health is.

The conflict lies in deciding whether or not providing environmental conditions so that the person can perform his present activities within tolerance is worth the resultant health difficulties several years hence. Some means for making such decisions must be generated. The burden would appear to fall upon those responsible (i.e., the customer) for system development. Therefore, what is required is a set of guidelines incorporated in the "A" score, wherein the customer would set forth rules for making decisions on selective employment of performance and health criteria where conflicts arise. This is a responsibility that would be purely his, and could only be made by him through consideration of the follow-on system(s), adjacent systems, and society at large. In fact, some decisions of this type may require his personal attention during the course of system development. These guidelines would be employed to derive the desired environment for every worker or contiguous group in the overall system environment.

Task 5. Calculate output requirements for safety and support system. — The objective of this task is to generate the values of the environments which the SSS means must produce to transform the "present" environment to the "desirable" environment. Table 2 and column 6 of Table 1 provide examples of needed SSS outputs to serve such a purpose.

TABLE 2. OUTPUT OF TASK 5
IDENTIFICATION OF ALL SSS OUTPUTS

MISSION PHASE	SITE NO.	SITE LOCATION	FACILITY	FUNCTION		NO. PEOPLE	ENVIRONMENT		
				OPERATOR	MAINTENANCE		PRESENT	DESIRABLE	SSS
(i.e., pre-flight, flight, postflight)	1	A	(e.g., building, station — other specific location)	(identification code)		7	(in terms of actual values to which personnel exposed)		

The last column would contain the actual output of the SSS means. This output would, in the case of atmospheric parameters (e.g., temperature, relative humidity, air movement, pollution), "make up" the differences which would exist between the "present" and the "desirable" values. For outputs relevant to preventive medicine and industrial hygiene, the last column would map out a health monitoring program aimed directly at the remote segment personnel. Periodic physical examinations and treatment for people who work in hazardous environments are exemplary of a method for sustaining man's performance through maintaining his health.

The needed SSS outputs should be couched in terms of what the means (man or equipment) should provide to the environment or to man. The examples in column 6 include specific values of environmental parameters (i.e., top entry) and personnel relations with the environments (e.g., sixth entry).

The sixth column should also contain the means capabilities for producing SSS outputs for the "usual" needs of man, e.g., sleep, nutrition, etc. In addition, work-rest cycle recommendations should be made for all remote personnel so that their performance may be optimized. This would probably result in the use of modified working shifts for some remote personnel.

The remaining three tasks produce the needed outputs of activity E-8. They are not discussed in much detail since the methods involved are well known, as mentioned earlier in the text.

Task 6. Perform gross functional design. — The goal of Task 6 personnel is to identify, using the output requirements for the SSS as determined in Task 5, the functions required to provide those outputs to remote segment personnel. A gross functional design is done for the purpose of isolating the major functions which must be performed and to identify the specific outputs which each function must provide to produce the required SSS output.

Task 7. Select means alternatives. — Based upon the gross functional design delivered from Task 6, Task 7 personnel would use the specified outputs of each function to select alternative means for implementing those functions. The alternative means would include both men and equipment to perform SSS functions. The costs associated with each alternative must be documented as well as the weight, power, and volume expenses for equipment.

Task 8. Generate means design, supporting data and detailed functional design. — In Task 8, the actual design of the SSS equipment and the specification of man's role in the SSS are defined. During Task 8, functions allocation efforts would be performed to decide the degree to which man should implement certain functions. Techniques which are useful for this purpose are documented in Report III of this series. The means design should be taken to the point of detail to allow activity G-7 (fabrication models) to be accomplished. This implies that complete physical characteristics, packaging descriptions, parts identification and breakdown, and interface characteristics between SSS equipments and between SSS equipments and others (i.e., prime equipment and maintenance equipment) should be clearly stated.

Discussion
Human Support System

In order to exemplify, but not to prescribe, the sequence of tasks by which activity E-12 might be implemented, we will discuss, in the following paragraphs, a ten-task procedure for activity E-12. The component tasks are identified in Figure 11 by means of simple output descriptions and a schematic representation of their interrelationships.

<u>Task 1. Identify critical functions</u>. — At this point in the development cycle, activity E-4 will have yielded detailed descriptions of operator functions. The local crew may have been allocated hundreds of functions over the period of the mission. Using a performance criterion, it would be extremely difficult to attempt an HSS design based upon, for instance, 200 or so operator functions, especially since the demands for support of man could vary from function to function.

Therefore, the goal of Task 1 is to decide some way of deriving HSS performance criteria from the total set of operator functions. A design which would allow varying man's support in the operational situation for the performance of <u>each</u> function (even if it were feasible) would not be cost-effective. Similarly, the use of mean, median, or modal performance reliability estimates (taken from all functions) as criteria would yield an HSS design which would not truly support man's capability to perform the functions positioned at the "tails" of the distribution, much less any functions in the middle.

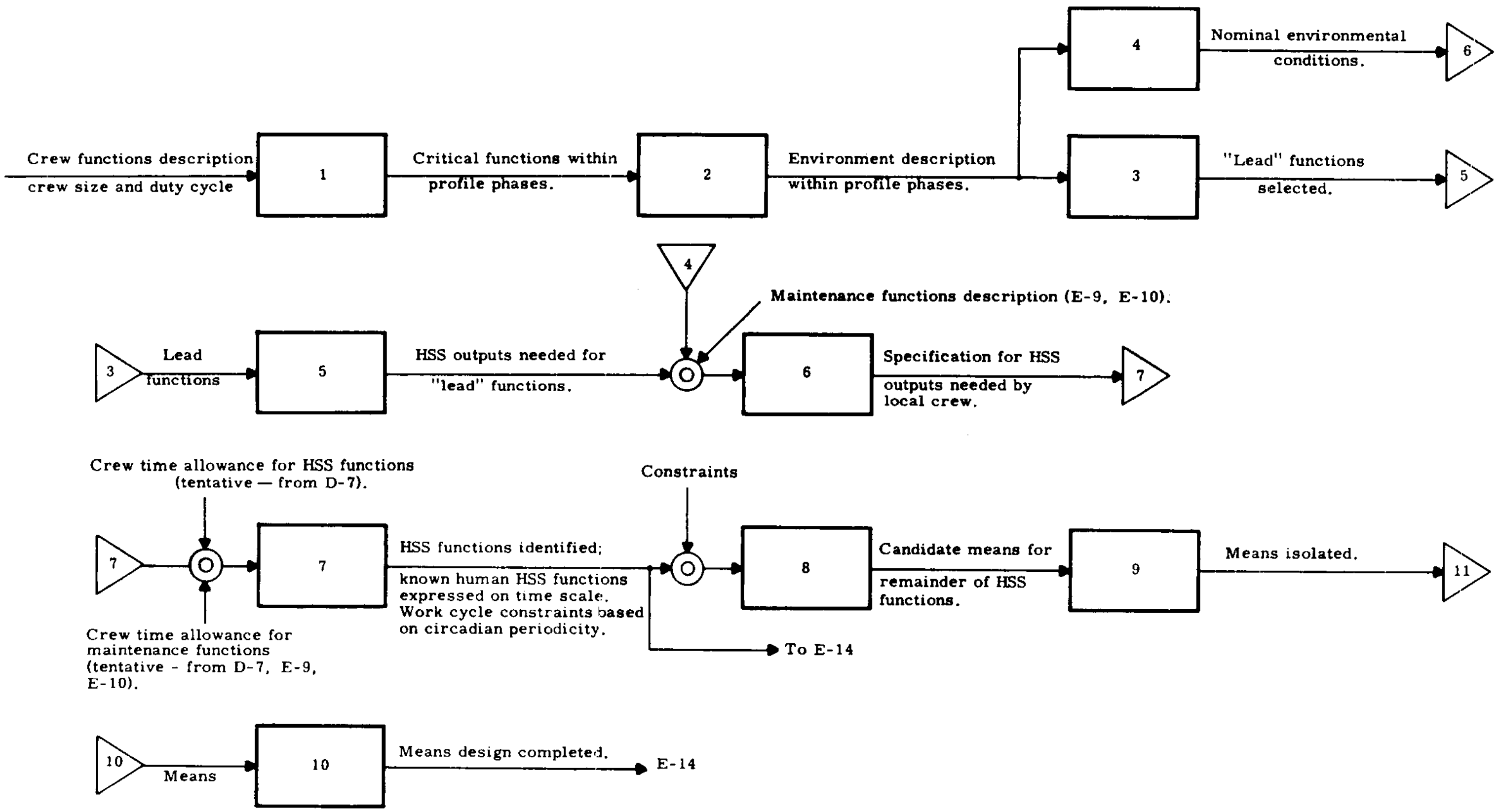

Figure 11. Major steps in HSS functional and means design.

One technique which appears reasonable involves the selection of critical functions, which essentially call for maximum physical and mental support for the man, from the total set of operator functions. Those which are critical would provide criteria for man's support. This technique has time-proven merit in that it is analogous to designing for the "worst conditions."

The first effort in Task 1 would involve creating criteria for criticality by which a subset of functions could be selected. It would be necessary to derive a weighting scheme so that the criteria selected could be ordered in terms of their ability to discriminate critical functions from the total set. These criteria would then be used to select the critical subset, which is the output of Task 1.

The input data needed to perform this task would be a detailed description of each operator function in terms of its required output, the tolerance within which the output must fall, the mandatory reliability with which the output is to be produced, the time required for the performance of the function, the position and frequency of the function within the mission profile. In addition, inputs would be required on the crew size, its duty cycle (i. e., the ratio of work periods to "off" periods within the mission), and the functions which are performed per each personnel position (i. e., the job description of the person or persons who would perform the function).

<u>Task 2. Describe environment</u>. — The business of Task 2 is to determine the performance-degrading properties of the intra- and extravehicular environment across the mission under which the critical functions selected in Task 1 must be carried out. If the degradation potential does not appreciably change across the profile, then Task 2 would merely involve identifying the environment as it would exist and affect performance. Descriptions of environmental conditions during the mission, as an input, may be largely obtained from the work carried out in activity D-7 (which is also the origin of operator function descriptions) and E-4. Environmental parameters to be described may include: "g" forces, temperature, pressure, etc. The critical operator functions selected in Task 1 may be compared against the environmental conditions by laying out the conditions and the functions along a

mission time scale. The placement or position of the functions along this continuum plus the changing environmental conditions will allow a comparison of conditions to functions.

Intravehicular conditions will also be necessary as an input (again from activity D-7). The intravehicular environment descriptions will only be estimates, based upon tentative HSS solutions worked out in a gross manner during activity D-7. However, advantage should be taken of earlier thinking (i.e., the literature) to enable hypotheses to be made concerning the likely environmental conditions when a nominal HSS is employed in the operational situation. Rather complete descriptions should be available in the current state of the art from previous space or aeronautical missions, depending upon the type of local segment. Such intravehicular data would be useful in characterizing the possible internal environment as the mission progresses.

One more subtask will have to be carried out to provide Task 3 with a meaningful input. Since the business of Task 3 is to select critical functions to use as criteria for HSS design, it is first necessary to relate the probability of man's performance degrading on critical functions to the environment to which he is exposed at any one point in the mission profile.

Task 3. Determine "lead" functions. — The objective of this task is to isolate the "worst" cases from the critical functions. These would serve as criteria for the development of the functional and means designs for the HSS. Criteria for performing this selection must be the first item of business. One criterion for selecting lead functions would be a high probability of performance degradation when carried out under stressful environmental conditions. A second useful criterion would be an extension of the first — the frequency with which the function must be performed during the mission under stressful conditions. Primarily, selection of lead functions would involve finding those critical functions the performance of which would expose man to the most stressful environmental conditions. Task 3 is essentially a repetition of Task 1, except now effects of stressful environs may be considered.

Task 4. Select nominal HSS values. — Once the environment has been described during Task 2, Task 4 would be begun as a parallel effort to Task 3. The end product of Task 4 would be a set of selected HSS outputs to provide for man's physiological and psychological requirements. These requirements will be those which are independent of requirements derived from man's continuing capability to perform critical functions. The nominal HSS outputs will be keyed to specific inputs necessary for man's general health and welfare. During Task 4, most of those HSS inputs which are noncritical function-specific (e.g., nutrition, personal hygiene) may be determined, based primarily upon the health criterion (rather than the performance criterion). Such nominal values are found in the literature and could be used as a starting point upon which to tailor an environment for the local crew to allow the optimal performance of its critical functions. The output of Task 4 becomes a necessary input to Task 6, which ultimately yields the HSS outputs towards which design efforts will be directed.

Task 5. Define HSS outputs for lead functions. — The objective of this task is to produce a set of human support system outputs needed to support the local crew members so that they may perform the selected lead functions with the necessary reliability. The outputs are stated in terms of values and tolerances, such as $72 \pm 5^{\circ}$ F for cabin temperature.

This effort would require scrutinizing the environmental variables which affect the crew's particular capabilities that are called upon in the performance of lead functions. The "lead" functions will have been chosen because one or more of man's capabilities required to carry out that function will be sensitive to one or more of the environmental stressors in the environment during the time when the function is to be performed. It is only necessary to identify the HSS outputs which will be required to support man's capabilities to perform the lead functions. (This is because nominal values are derived during Task 4.) The manned lead functions which would have been selected are those which expose the personnel to a broad spectrum of environmental stresses.

Table 3 provides a possible data documentation format for expressing the output of Task 5. The human capabilities needed to perform each function would be listed. The expected values of the environmental parameters thought to stress the capabilities would be listed under the environmental heading. In the next column would be documented the anticipated time under which the stressor would be present in the environment. The following column would explain the frequency with which the function would have to be performed within each duration. The next column would indicate the probable effect of each environmental stressor if no support measures were taken to minimize or nullify its effects. The final column provides the heart of the output of Task 5. The entries would be in the form of the value of the environmental stressor which would be tolerable to the crew members so that their functions would still be performed as required.

TABLE 3. OUTPUT OF TASK 5
IDENTIFICATION OF HSS OUTPUTS FOR LEAD FUNCTIONS

MISSION PHASE	LEAD FUNCTION	PERSONNEL INVOLVED	PERSONNEL CAPABILITIES	STRESSOR(S)			EFFECT	TOLERABLE ENVIRON. VALUES
				TYPE	VALUE	TIME		

It should not be construed from the above discussion that the environment should be "ideal" (i.e., nonstressful). Using performance capability as the primary criterion allows an environment to be created which can include some "normal" stresses.

Task 6. Derive required HSS outputs. — This task is essentially one of comparing and integrating the nominal HSS outputs with the outputs derived through consideration of lead functions. As a means for checking the ability of the derived outputs to support man fully, a description of man's maintenance functions must also be used. This would be especially important if the crew is to be capable of performing extravehicular maintenance on a space flight. Investigation of maintenance functions would uncover peculiar means requirements for protective clothing, for instance, which might not be discovered if man were considered only as one who performs operator functions. During Task 6, both criteria come together: the man must be supported so that he can perform (Task 5); he must be supported so that his physical and mental health remain within bounds (Task 4).

Therefore, the output of Task 6 could be envisioned as a comprehensive list of inputs to man from his environment (e.g., so much oxygen, humidity, food, etc.), inputs from, or interaction between, crew members, and suspected outputs from man which could in turn affect his health (e.g., microbial and physical contaminants, waste products, etc.). In other words, the output of Task 6 is comprised of all data required to produce both a functional design and a means design for the human support system. The environment to which the crew will be subjected within the cockpit or within the space cabin, as the case may be, must be specified. In addition, the reliability with which each HSS output must be provided to the local crew must be defined. The HSS outputs must be qualified as well by the imposition of a tolerance on each output value beyond which the output should not be allowed to vary for the given reliability.

The HSS outputs are really those environmental conditions which enable desired responses to be elicited from the crew. Within the total set of desired responses falls the individual's ability to interact with the other members of the local crew so that a cordial environment is maintained. Some of the HSS outputs, such as the psychological health of the individual and the nondiseased state of his physical being, may have to be considered or expressed in a negative fashion. For instance, in terms of his behavioral characteristics, it might be better to define as an HSS output the behaviors which are unacceptable to the emotional equilibrium of the crew. Similarly, requirements for physical states of health may also have to be expressed in such a fashion.

Another output would be an expression of the capability which the HSS must have with regard to the handling of waste products which emanate from man or which result from his activities. Bacteria, feces, urine, wash water, insensible water, waste paper, trash, lint, fingernail clippings, hair, skin cells, etc. are examples of wastes from man which must be processed by the Human Support System. Man also affects the temperature and humidity of the environment, the controlled movement of air and its composition. An HSS "output" to handle these types of endogenous conditions would have to be couched in terms of the expected quantity and type of matter and energy produced by man physiologically and effected by his physical presence which could be conceived as an input to Human Support System means which must process it. The output in this case would be the end result of the processing in terms of acceptable levels, for instance, of contamination (e.g., bacteria) which the HSS could allow the crew to be exposed to, subsequent to processing.

Task 7. Perform gross HSS functional design. — The functional design establishes requirements for the HSS means design. It identifies each of the functions which man or equipment would have to perform to yield the necessary HSS outputs, (determined in Task 6). The output state of each function should be expressed, depending upon the ultimate HSS output sought, in the relevant units of measurement (e.g., 50 $\pm$ 10% Relative Humidity) to allow means designers to provide for the desired HSS outputs.

A functional design is important because its creation assumes no equipment bias (in the purest sense). However, when a functional design is carried to detail, or presented in such a manner that only one type of means could provide the HSS outputs, then one is approaching means design. (A detailed functional design is developed in conjunction with a possible means design.)

The gross functional design may be characterized by input states, function boxes, and output states except that values and tolerances should accompany each output. Figure 12 is presented as an example of a gross functional design to produce a needed HSS output.

Some means design may take place at this time with respect to assigning some function to the crew. Several HSS functions will have to be performed by man (e.g., sleeping, eating, urinating, etc.). These may be identified at this time. All those tasks or activities which man would have to engage in to maintain himself, such as sleeping, eating and bathing, can be specified. Time requirements to perform these vital manned functions should also be declared. During activity D-7, an apportionment of man-hours (e.g., per day) to be devoted to operator tasks would have been made. Also in D-7 consideration of time was given across all three types of functions. On the basis of this, a recommendation of crew size was made. The remainder of the 24 hours would be available for maintenance functions and HSS functions. By the time the E set of activities is being accomplished, crew size is set, providing a constraint for time apportionment to man for maintenance and HSS functions. Task 7 personnel will require information from activities D-7, E-9, and E-10, on the amount of time being recommended for operator and maintenance tasks. Some trade-offs will have to occur between activities E-12 and E-9 and E-10 to decide what functions are most important to probability of mission success. These trades will result in time apportionments to maintenance and HSS functions.

The Human Support System functions which man will have to perform should be laid out on a time scale, so that a cumulative total may be derived for comparison and trade-off for the remainder, after time allowances for operator functions are made. Some adjustment will probably have to be made between maintenance and HSS function time allowances.

HSS Output Required: 10 lbs water/man/day

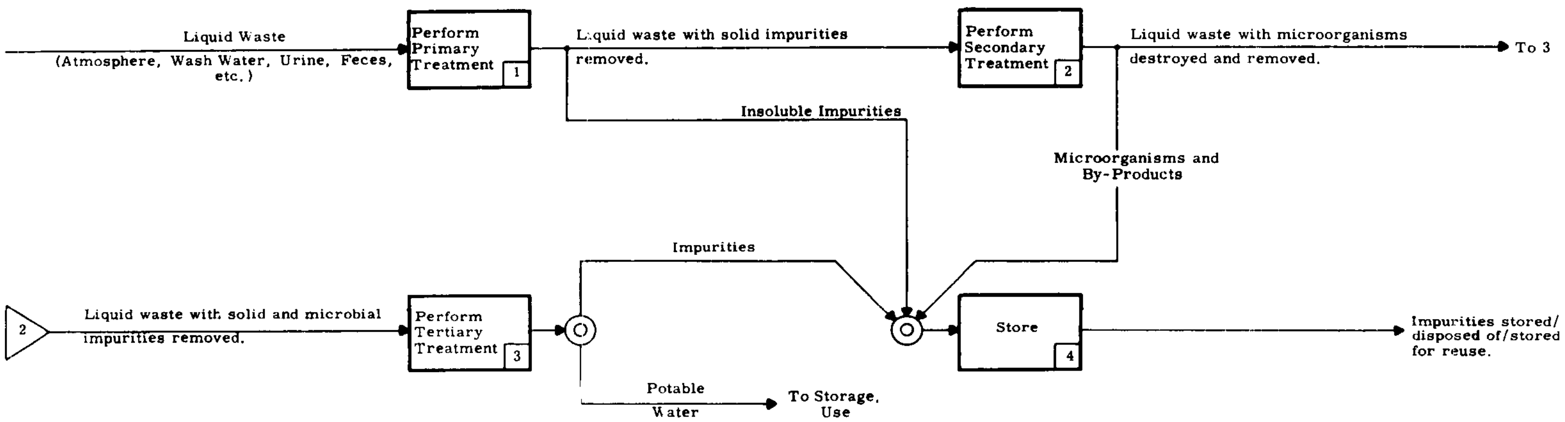

Figure 12. Exemplary gross functional design — Task 7
Water Reclamation Subsystem *

* This example would probably only be relevant to a manned spacecraft on an extended mission. An aircraft would depend largely upon an open cycle rather than the type depicted above.

Data would also be forthcoming out of Task 7 with respect to constraints on the schedule of work for the local crew within the 24-hour period. These data will be recommendations for the most part, as to when, during this period, man should be engaged in useful work, and when he should be allowed to relax, based primarily upon man's performance fluctuations due to circadian periodicity. The actual work-rest cycle for the local segment crew would be stabilized subsequently at the "subsystem" level on the model.

The above seven tasks are the precursors for actual means design of the Human Support System. As discussed during the early part of the Discussion section, the first seven tasks are those which are peculiar to HSS development. Subsequent functions would essentially be those with which every designer is familiar: isolation of alternative means for the performance of the nonmanned HSS functions; trading off to select specific means from alternatives generating a detailed functional design for use in developing training programs (in G-13) and job aids (G-15); finally, the integrated design and testing of all means required for the implementation of the Human Support System goals.

Tasks 8, 9, and 10. — These tasks are concerned with the selection of means by which to implement the functional design of the Human Support System. The sequence is a familiar one in which candidate means are identified and alternative configurations are matched against overall requirements for the HSS until a configuration is found that is most satisfactory. This set of means is then identified in sufficient detail to permit the development of fabrication models. Typical Human Support System equipments that may be called out are identified in Table 4.

TABLE 4. TYPICAL HSS EQUIPMENT BY CATEGORIES.

	Major HSS Means Categories	Representative Equipment
1.	Life Support - Environmental Control System	Atmosphere gas supply and composition control, pressure control, temperature and relative humidity control, CO_2 reduction, trace contaminant and bacteria removal, water management, waste management.
2.	Medical and Psychological Monitoring and Support	Diagnostic instrumentation for: cardiovascular system, nervous system, digestive system, endocrine-metabolic system, musculoskeletal system, respiratory system; psychological tests for: cognitive, perceptual, and affective capabilities/state, performance decrement.
3.	Hygiene	Bathing equipment, shavers, etc.
4.	Recreation and Sleep	Recreation equipment (e.g., games, books). Bunks, clothes storage.
5.	Exercise	Exercise equipment: bungee cords, ergometer.
6.	Food Management	Food supplies, "kitchen" gear, etc.
7.	Housekeeping	Soap, towels, etc.

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X. DESIGN FOR RELIABILITY OF PERFORMANCES AT MAINTENANCE TECHNICIAN INTERFACES

Activity Group Requirements and General Considerations

Maintenance as used in this chapter includes those actions by man which prevent an equipment from breaking down or which restore an equipment so that the outputs of the functions which it implements will be in tolerance. Maintenance is required in systems only when the available means for implementing the functions in the system have inherent reliabilities less than that required to meet the probability-of-output goals for the functions.

The decision to include man in maintenance actions (assuming that they are required) is made prior to the initiation of this activity group (in activity E-5 or E-9). Once the decision has been made that man shall participate in maintenance actions, a number of follow-on decisions are required, including consideration of what design features and characteristics must be built into the equipment or supplied in supportive equipment to enable man to perform the required actions. It is with this final decision area, design of equipment, that this "human engineering" activity group (activities F-6 and F-9) is concerned.

The requirement for this activity group is the result of prior decisions that maintenance must be performed, and that man shall be included in specific maintenance loops. The outputs of this activity group include recommendations, specifications, and drawings showing how the equipment shall be designed to facilitate man's performance of these maintenance actions in order that system requirements for quality (probability of success) are met. In addition, of course, the output must also show that these recommended design features will be within alloted costs.

The design interface between man and machine must provide the capability for meeting the requirements for communication by the machine to the man and control of the machine by the man. These requirements exist for operator performance interfaces as well as for maintenance performance interfaces. There are, however, significant differences in the types and degree of communication and control required in the maintenance situation, as opposed to the operation situation.

In the operation of equipment, control of the equipment might be thought of as exercised by man through the manipulation of control devices normally located on the exterior panel of the equipment, or centralized on a console. In the maintenance utilization of equipment such control is ordinarily exercised only to verify the correct operation of the equipment or to isolate a malfunction within the equipment. In addition to this, the maintenance technician must also utilize his own physical performance capabilities to exercise direct control over the parts, components, and units within an equipment. For example, the maintenance technician must gain access to the interior of an equipment to physically remove or control a malfunctioning tube or circuit board. The primary implication of this type of control with respect to the overall design of the equipment is that for maintenance purposes consideration must be given to the total design of an equipment, including the internal arrangement of components and parts, as well as the means for gaining access to this internal arrangement. This contrasts with the operation aspects of the equipment where the emphasis is placed on the externals of the equipment, such as the arrangement of displays and controls on a panel, and is only indirectly concerned with the physical interior of the equipment. Although it is obviously true that an operator's control knob or handle has three dimensions, the difference between human engineering for operator performance and human engineering for maintenance is essentially that of considering three dimensions rather than simply the surface dimensions.

The man-machine interface for maintenance differs from that for operation in a second significant manner, the variety of actions. Although there has been a trend towards the development of general purpose equipment for operation, particularly information displays, most operator performance panels and consoles are designed to accommodate a limited number of performance sequences. In many cases they are designed for a single sequence. This means that displays and controls can be laid out to facilitate this single sequence without having to consider alternate sequences. This greatly simplifies the design of the interface. The maintenance interface, however, must accommodate a wide variety of performances by the maintenance technician. Maintenance actions for a single equipment may include calibration, removal of the unit or its components, servicing, troubleshooting, to replaceable components or modules, mechanical adjustment, and many other actions depending on the nature of the equipment and the maintenance requirements. Design of the interface must, therefore, include consideration of all these different performance sequences. It is almost inevitable that there will be design conflicts between those various sequences as to the location or design of the equipment components. A location of an access door, for example, that might facilitate the removal of a power supply might hinder the removal of a preamplifier unit. In addition to the conflicts among maintenance performance sequences, undoubtedly there will also be conflicts with the optimal arrangements developed for operator performance. This is true because the same displays and controls used in operation are also necessary, in many cases, for maintenance actions. In troubleshooting, for example, the starting point for malfunction isolation may be the report of a crew member as to the condition of the equipment as evidenced by the displays and controls that he utilizes in operator performance.

The multi-action nature of maintenance is true not only for the maintenance technician but also for test equipment used by the maintenance technician. To stay within cost and quality constraints it is often necessary to utilize test equipment with more than one prime equipment unit. This means that the design of this test unit must accommodate, and hopefully optimize, multiple man-machine interfaces. This is difficult to accomplish without imposing high performance demands on the technician, or increasing the probability of human error in using the test equipment.

This activity group (F-6 and F-9) is concerned with the following types of maintenance interfaces:

(1) Direct physical interface with the prime equipments.

(2) Indirect interface with prime equipments via mobile maintenance or test equipments.

(3) Interface with maintenance equipments to accomplish maintenance on prime equipments.

(4) Interface with maintenance equipments, both direct and indirect, to accomplish maintenance on the maintenance equipments.

(5) Direct and indirect interface with human support system equipment to accomplish maintenance on the HSS equipments.

This maintenance activity group (F-6 and F-9) is concerned with both the local and remote segments of the system. For the purposes of this activity group, there must be close interaction between the development of maintenance interfaces for each of these segments. This is particularly true because many of the maintenance actions will be accomplished by the remote segment on the local segment. Examples of this interaction between the segments can be cited for all classes of systems. For example, a number of "fixes" of unmanned satellites have been accomplished from ground stations by utilizing telemetry signals and the on-board sensors and mechanisms of the vehicle, which have not always been designed for such purposes. In the case of manned orbital vehicles, the interaction may consist of providing maintenance information to the flight crew of the space vehicle. Finally, in the case of manned aircraft, most maintenance is accomplished for the local segment by the remote segment prior to, and following a mission.

Relationship of the Group to the Development Cycle Model

Human engineering recommendations must be developed for both the remote and local segments for maintenance interfaces. As indicated in the preceding section, the development of these recommendations is closely related. For the purposes of this discussion, however, the emphasis will be placed on the local segment. Differences between these parallel activities, and implications of the local segment for the remote segment will be identified.

Although the only activities specifically responsible for the human engineering of maintenance interfaces are F-6 and F-9 for the remote and local segments respectively, these activities are closely related to, and dependent upon a number of preceding activities in the development cycle model. The first specific recognition of man's participation in maintenance actions occurs in Phase II in activities D-4 and D-7. In these activities, the primary focus is placed on the allocation of operator functions to the crew. However, these allocations and the development of recommended crew sizes must be based upon consideration of parallel developments in the hardware-related activities, which are concerned with potential means for implementing the system and the reliability of those means. As indicated earlier, maintenance becomes a requirement when the inherent reliability of an available means falls below the probability-of-output requirement for the function it implements.

In Function E, specifically activity E-9 (or E-5), requirements for providing needed reliability are considered and allocations are made to man, when his participation represents the most effective solution to the reliability problem. This results in a definition of those maintenance actions in which man is required as a component. Evidence must be produced at this time which shows that resulting maintenance interface problems are solvable.

A third activity which directly affects the human engineering of maintenance interfaces is activity E-11 which provides recommendations for the "human engineering" of operator interfaces. Although this activity does not provide consideration of maintenance actions, it establishes constraints in the sense that it provides recommendations for human engineering of the equipment and workspaces to meet the human performance requirements with respect to operation of the equipments. The solutions provided may be optimal with respect to the requirements of the activity, namely operator interfaces, but may cause problems for the human engineering of maintenance interfaces. This is particularly true with respect to the layout of the workspace. For example, efficient operation activities require a maximum of centralization of activities. This is desirable from the point of view of man as an operator. Usually, however, it is undesirable from a maintenance viewpoint since it tends to make access to the equipment difficult and imposes certain difficulties in utilizing operational displays for maintenance purposes. Thus it will be necessary for E-11 to consider the maintenance interface implications when making their recommendations. It must be noted, however, that easing of maintenance technician performance can be justified only in terms of needed reliability gains achieved; ease of access, for example, is not a goal for its own sake.

At the same time that design of maintenance interfaces is being accomplished (F-9), parallel activity is going on in activity F-10. This activity is responsible for recommending required maintenance performance for the HSS equipment, and for maintenance equipment. This activity stands in the same relation to F-9 for these equipment, as activity F-9 does for the prime equipment. Since this activity is in parallel with F-9 in the development cycle model, close interaction is possible and design problems on maintenance interfaces should be minimized.

A second parallel activity of interest is F-8. This activity is concerned with techniques for maintaining the performances of personnel in accomplishing the maintenance requirements of the local segment. It is with this activity that maintenance interface design must interact and conduct joint trade-off studies to determine whether maintenance performance capability must be designed into the equipment for the crew, or whether selection, training, and job aids can ease the requirements for human engineering of the maintenance interfaces.

Subsequent to the completion of the activity for human engineering of maintenance interfaces, there is no activity solely charged with this responsibility. In Function G, the recommendations of the maintenance interface activity will be implemented within the hardware activities through the incorporation of recommended designs in the fabrication plans for the hardware elements. In Function H, the validity of the incorporated designs will be tested as a part of the overall tests of the personnel products package in activity H-14 and in activity H-16.

In the event that recommendations for maintenance interfaces prove inadequate in subsequent testing, there will, of course, be a necessity for retrofit in this area. The typical retrofit need which arises involves unforeseen obstructions in the maintenance workspaces. Fortunately, the offending equipment is often easily modified to remove the obstruction. Sometimes, however, this modification is not at all easy, and requires expensive, time-consuming redesign. If there are no inadequacies in the recommended designs, then the real work of this activity will be completed in Function F, barring any changes in system requirements or technological failures in other areas which might impact the maintenance interfaces.

Resources Needed

Ideally, the staffing of this activity group would be drawn from personnel who had participated in earlier activities in the development cycle which relate to the design of maintenance interfaces. Although it is unlikely that complete staffing can be accomplished in this manner because of the demand from other activities for such services, it should be mandatory that at least some of the personnel assigned to this activity group be selected from the pool of personnel associated with the earlier stages of the development cycle. This is critical not only for the reason that they know the system, but they also know the candidate solutions that were considered and discarded.

Preceding activities which would provide a source of staffing for this activity group are those activities that recommend which functions should be done by man (D-7, E-9, and E-11).

Activity D-7, which deals with the allocation of operator functions and the development of recommendations for crew size, would provide personnel who are familiar with the early stages of the system development. Additionally, they would have already considered the conditions imposed on crew members of the local segment by the operational environment. Such data from the operator considerations that were primarily dealt with in the D-7 activity would be generalizable to the maintenance performance area.

Activity E-9 is the most critical input to the maintenance interface activity group since this is the activity that determines what maintenance actions man will participate in, and makes preliminary selections of the way in which he will participate. Obviously, such personnel would be thoroughly familiar with all of the candidate approaches that were considered in this activity. It is also true that such personnel would be requirements-oriented, which would provide a balanced combination with the more hardware-oriented personnel who are also required for properly implementing this activity.

A third potential source for staffing the F-9 activity is activity E-11, the human engineering of operator interfaces activity. Although the primary concern of these personnel in their original activity is man's operator performances and a consequent focusing on the externals of the equipment, they would be valuable both for their knowledge of the selected means and the constraints imposed by operational requirements.

In general, this activity should be staffed by personnel who may be described as a cross between maintenance engineers and human engineers. In all cases, it is highly desirable that personnel associated with this activity be experienced with the real field problems of maintenance, both in the remote and local segments. The reason for this requirement is the fact that although it is often straightforward to simulate the operational performances required in a system, and to a large extent the operational environment in which the performances must occur, it is considerably more difficult, if not impossible, to adequately simulate all of the environmental forces (both man and nature) that impact on the maintenance actions in a system. Therefore, it is necessary to have the most experienced personnel when designing and testing the interface equipment, in order to consider all of the potential effects that these factors may have on maintenance performance capabilities.

In addition to the technical personnel discussed above, this activity should have available support personnel to deal with the cost element aspects of maintenance interfaces, and to provide the test facilities required for verifying the efficacy of the proposed solutions to the maintenance interface problems.

The requirement for equipment and facilities to support this activity is primarily with respect to test facilities. The principal type of testing required for this activity is in the use of fairly sophisticated mock-ups of the local and remote segments of the system. These mock-ups must be somewhat more sophisticated than those used for the operator aspect of the system because of the fact, pointed out in earlier discussion, that a maintenance interface involves the internal as well as the external configuration of equipment.

Design of All Maintenance Interfaces and Workspaces
Activity F-6 (Remote)

This activity must produce recommendations for solving interface problems between maintenance technician performance and the hardware involved in maintenance technician performance. Maintenance technicians interface not only with the hardware to be maintained, but also with hardware which is employed for the purpose of carrying out maintenance. The output may include recommendations for the design and packaging of hardware, and recommendations with respect to the training of maintenance technicians and to job aids, where training and job aids can be employed to alleviate interface problems. The output of F-6 is concerned with the remote segment.

The input to this activity derives from F-3, a personnel products technical management function. This input will specify the manner in which the solutions recommended will be evaluated. Evaluation will be basically related to overall probability of system success.

Activity F-9 (Local)

This activity is concerned with the design of maintenance interfaces in the local segment. Its output must contain recommendations for solving interface problems. That is, its output must recommend job aids or training, or equipment design solutions wherever required to provide for the proper articulation of maintenance technician performance with the equipment employed in maintenance, and with the equipment being maintained. The criteria for proper articulation will be given in the input which derives from F-4. The input will also state the constraints within which recommendations must be made. They will be the typical constraints that must be observed in the design of the local segment.

Discussion

The specific initiating inputs for the human engineering of maintenance interfaces of the remote and local segments are provided by activities F-3 and F-4. These two activities are in the personnel products technical management group. As such they must provide the specifications and requirements for the various personnel products activities, as well as ensure that the imposed requirements are met by the concerned activities.

In effect, these initiating inputs establish specifications for what must be accomplished within the maintenance interface area, and define the techniques and procedures for measuring whether or not the outputs meet these specifications.

With regard to the maintenance interfaces, the personnel products activity group will allocate requirements based primarily on the results of activities E-5 and E-9 which determine what maintenance functions are to be performed on the prime equipment. The allocation of these requirements to the maintenance interface activity does not specifically constrain how the required quality may be achieved, but it does specify precisely what quality is necessary in terms of how that quality would be measured. It does not, for example, specify a "level of automation" that should be utilized in check-out functions but simply that check-out must be achieved within specified constraints of time, weight, power, etc..

A critical aspect of this "work statement" imposed by the initiating activity is the question of the tests or demonstration to be used in measuring the quality of the output of the maintenance interface design activities. Specification of these tests and demonstrations will dictate, to a large extent, the types of internal interim testing that will be accomplished with the maintenance interface design activities, since it is necessary to anticipate any potential "no go" situations prior to the completion of the activity. This specification should not, however, limit the maintenance interface activity from utilizing other nonspecified tests for measuring the degree of progress in achieving specified objectives.

The first task in response to these requirements is the organization of the data resulting from these previous activities. A typical five-task approach to activity F-9 might proceed as follows, starting with data organization.

Task 1. Review functional allocations for maintenance of prime equipment. —The output of activity E-9, which results in a recommendation of maintenance functions that must be performed on the prime equipment, will result in an identification of each occurrence of an intersection of a maintenance function with a piece of prime equipment. Depending upon the degree of equipment design available, the equipment side of this intersection may be defined at as gross a level as a subsystem, and at as fine a level as a specific end item of equipment, or even possibly a subassembly or component. Regardless of the level of detail of this output, it must first be organized to facilitate the accomplishment of the maintenance interface design process.

The objective of this organizing task is to identify related equipment items so that an integrated approach to maintenance design may be developed for each unit or subsystem configuration. Such an organization will minimize the possibility of developing design approaches which are internally inconsistent within the equipment framework.

To facilitate the organization of the maintenance functional data, the initial step (if it has not already been accomplished) is to organize the material into an equipment-by-maintenance-function matrix. Cell entries in this matrix should identify the following characteristics of the intersection.

1. Estimated human performance capability required for performance of the maintenance function.

2. Time constraints imposed on the function as a result of the relation of the affected equipment to the mission profile.

3. Unusual work-environment considerations. For example, in a space mission must the maintenance be performed outside the vehicle?

4. Typical layout of the equipment with respect to other equipment in the system.

5. Required frequency of performance of the function if it is periodic in nature, or estimated mean time between failures if it is a corrective function.

Once the matrix is completed, it would be possible, of course, simply to assign each cell of the matrix to a human engineer for the development of a design solution to the intersection. This approach is inefficient, however, because it increases the likelihood of incompatible solutions to the design problems, and increases the likelihood of duplication of effort. The next step, therefore, should be a systematic reduction of the matrix to a minimal number of design packages requiring solution. This reduction of the matrix should be made using the following commonalities.

1. Similarity of requirements with subsystems. For example, there may be a number of functions within a subsystem all of which require the same procedure for gaining access to the internal configuration of the equipment. This preliminary procedure should be developed once, and then applied to all relevant situations.

2. Common location. Based on the matrix entries, locational packages may be identified where the human engineering, particularly of the workspace layout, requires a single design approach. This approach applies particularly to the area of extravehicular maintenance for space missions.

Application of the above grouping principles to the function-by-equipment matrix should result in the reduction of the matrix to a manageable set of design packages for assignment to human engineering design individuals or teams. The requirements for each design package consist of the summary of entries in the cells with the additional suballocation of cost elements assigned to the maintenance interface design activity.

Task 2. Develop candidate design solutions. —The development of candidate design solutions for each of the identified packages might come from one or the other of the following sources.

1. Candidate solutions proposed and studied in activity D-7 in which man's basic role in the system is defined. These solutions will, of course, require further study and development to determine their probability of success within cost and quality limits.

2. Similar systems. Many of the design solutions for performance as well as maintenance are rooted in extrapolation from solutions that have worked in similar systems in the past. The danger here is that the requirements associated with the older system do not match those of the system under development. Included within this area is the general experience of the design personnel with the maintenance technology existing at the time of the system development cycle.

In the case of advanced systems, often the system under development is the first of a kind. Therefore, there is no operational experience available to aid in the selection of a particular candidate design. In these situations, it is usually necessary to make extrapolations from experimentally derived data. This is particularly true at the present time with regard to the design of space systems for which little operational data is presently available, e.g., extra-vehicular maintenance. In such cases, the actual selection of a particular candidate design must rely on experimental data obtained during simulation of the expected operational environment.

Each of the proposed candidate solutions must, of course, be screened prior to testing to ensure that there is a reasonable probability that the approach will meet the requirements for that design package contained in the function-by-equipment matrix cells.

Task 3. Test candidate solutions. —Testing of maintenance interface design solutions will be guided by the specifications imposed by the personnel products activity group through activities F-3 and F-4. During pilot or preliminary testing, it may be necessary to deviate from the specified tests until an initial determination is made of the feasibility of the approach. In general, the testing of maintenance interface designs is accomplished through table-top paper validation of the approach, or through some form of simulation. Table-top validation is usually necessary as a preliminary to full-scale simulation, but may not be acceptable as final demonstration unless there is no way in which simulation can be accomplished.

Within the possible approaches using simulation, the following three types are appropriate to the problems of maintenance interface design.

1. Mock-ups (Static). Static mock-ups may be either soft or hard versions of the proposed equipment configuration, depending on the state of development of the configuration and the time and money available for the test program. Mock-ups are particularly useful for testing accessibility of equipment for removal and replacement maintenance actions. One difficulty that may be encountered in this technique is that since maintenance is dealing with the total configuration of equipment, both internal and external, the cost of such complete mock-ups may be prohibitive.

2. Mock-ups (Dynamic). Dynamic mock-ups usually consist of hard mock-ups that are activated either under manual or computer control. The techniques used in activating these mock-ups may be simply a simulation of the inputs and outputs of the system rather than a working prototype. The primary advantage of this testing approach over static mock-ups is that it enables collection of data regarding performance times of maintenance actions in a dynamic environment. This is particularly important if the actions are externally paced for the maintenance technician. That is, if he must perform within time constraints imposed by the equipment, rather than pacing the action at his own speed.

3. Computer simulation. The final category of testing deals not with man-in-the-loop simulation, but rather with computer simulation of

the maintenance situation using a form of mathematic model. This type of simulation is particularly effective for determining the effects of overload on maintenance performance under unusual situations in which a number of maintenance actions are required essentially simultaneously. Computer simulation is also very effective for identifying potential conflict areas between various design package solutions that have been developed independently.

Task 4. Analyze test results and select design solutions. —Based on the results of the test program, candidate solutions will be selected for each of the design packages. This initial selection must be verified through computer simulation (or other appropriate techniques) to ensure that there are no conflicts within the maintenance interface design areas.

In the event that the optimal design solution for maintenance is in conflict with established equipment or workspace layout resulting from the human engineering of operator interfaces, trade studies should be conducted to see if there is an acceptable alternative from the operator viewpoint that is not in conflict with maintenance requirements. Although interface designers will naturally endeavor to avoid such conflicts, it is inevitable that they may occur and must be resolved.

Task 5. Implement design solutions. —After selecting the proposed or recommended design solution for a maintenance interface package, and ensuring that it is not in conflict with other aspects of design, there still remains the task of implementing the solution. By this is meant the preparation of detailed drawings and specifications of the proposed solution. It also means the preparation of the supportive data for the approach sorted out during the testing program.

The above approach must also be applied to the design of maintenance interfaces for the Human Support System, and for maintenance equipment. After completing the design solution for the prime equipment, the same tasks must be performed with reference to the Human Support System and maintenance equipment.

A critical difference in the approach to the HSS and maintenance equipment is that these tasks are performed in parallel with the determination of the required maintenance functions associated with the equipments, rather than after the fact as was true of the prime equipment. This requires close interfacing among the concurrent actions.

The required maintenance functions for both maintenance equipment and the HSS are determined in activities F-7 and F-10. For practical interface with these activities, personnel assigned to human engineering design of these interfaces should function in concert with personnel from the lead activities.

Another area of interface of direct concern to the design of maintenance interfaces is that occurring in activities F-5 and F-8. These two activities are concerned with the maintenance of maintenance technician performance in the remote and local segments respectively. Trade-offs with those activities are required in the development of candidate design solutions of maintenance interfaces since these are the activities concerned with the selection and training of personnel to implement the maintenance actions. Maintenance interface design must at all times be sensitive to the human performance capabilities that will be available for implementation of the design solutions either as a result of training or selection.

Research Note

Maintenance interface design activities are primarily concerned with design and demonstration of maintenance or maintainability, rather than maintainability prediction. The primary lack in this area is not with regard to techniques for selecting what actions must be demonstrated, but rather specifications of the conditions, environmental and personnel, that constitute an adequate demonstration of the maintenance actions.

Activity F-9 (Local)

The primary output of this activity is the recommended human engineering design package for maintenance interfaces of the prime equipment, maintenance equipment, and Human Support System equipment. The design package will consist of such things as engineering drawings of maintenance interfaces, specifications for equipment, and procedural or technique descriptions required to implement performance of the required maintenance actions. These are things which are produced for the benefit of the development cycle, and are not end products of development. Their purpose is to assure that the operational system means will be capable of working together to produce the required system quality.

At this point, the development strategy which we are using becomes apparent. In any development cycle what is really required is a collection of means which, when joined together, will produce an operational system of the required quality. Conceptually, a system designer could take all possible means that exist in the world and put them together (on paper) in all possible combinations, and pick that combination which produces an operational system of the highest quality. As it turns out, such a thing is fantastically unfeasible. Therefore, development strategies are devised which enable the designer to come up with an operational system of satisfactory quality without resorting to brute force methods of exhaustion. In fact, the need for human engineering of maintenance interfaces in our development cycle model is part of our strategy for achieving an operational system as efficiently as possible. Briefly, this strategy says that the major equipment should be designed <u>first</u>, and only then do we worry extensively about the compatibility of this equipment with the people who must maintain it. Notice that this procedure is clearly imperfect, for the exact human engineering implications of the maintenance on a particular piece of equipment bears heavily on the desirability of that piece of equipment. Nevertheless it beats having to take all combinations of equipment with people to see which is the most desirable.

The objective of any activity in a development cycle is, of course, ultimately to enable us to select the means and the procedures for hooking them together such that an operational system of high quality will result. Therefore, any activity in the development cycle (including this human engineering activity) must be judged by the extent to which it can contribute to our selection of the means and the way of hooking these means up to produce a high quality system. Now the human engineering activity may produce engineering drawings, adaptation equipment, or even prescriptions for pep pills to keep the maintenance men awake during long maintenance stretches. But whatever the items are which are produced by this activity, they are ultimately judged by their contribution to the selection and assembly of the means to produce a high-quality operational system.

In addition to the primary outputs of this activity which we have alluded to above, this activity must also produce a data package demonstrating that the primary outputs are good. Therefore the data package must demonstrate that man can relate with the other system means in such a way as to produce a high-quality operational system. Now to show such a thing is a <u>very</u> big job, and many of the things which would have to be shown are not in the realm of what is ordinarily thought of as human engineering of maintenance interfaces. However, all the other activities within the development cycle must also produce similar kinds of data which demonstrate that <u>their</u> products yield a high-quality operational system. Therefore, we may expect a great deal of help in the preparation of this data package from other activities within the development cycle. In fact, perhaps the preparation of this data package may be viewed as a joint effort of the personnel in this activity with the personnel in many other activities in the development cycle. The contributions to this data package from personnel in this activity might include such things as: demonstration that the workspace available for maintenance is adequate for man to use, demonstration that the lighting available at maintenance points is adequate, demonstration that parts can be removed without the requirement for a third hand on each maintenance man, or, finally, perhaps the demonstration that the maintenance tools provide the assistance which is required in the operations which they are to support. Some of these demonstrations may be provided by walking a human being through maintenance actions in a mock-up operational system.

In both the remote and the local segment, human engineering efforts are present because of their beneficial effects on the cost and quality of the operational system. If any <u>one</u> big difference is to be pointed out between human engineering in the remote segment versus human engineering in the local segment, it might be that the human engineering efforts in the remote segment typically produced beneficial effects on system costs, whereas human engineering efforts in the local segment typically produced beneficial effects on system quality. Thus, in the local segment (particularly in the case of long-duration missions) superordinary human engineering may be an absolute must to prevent ultimate system failure. If, for example, the maintenance tasks, because of seemingly innocuous obstructions within the equipment to be maintained, cause even moderate extensions in the time required to perform the maintenance, then delays for repairing equipment failures can become longer and longer until total system failure results. In the remote segment, such a situation can ordinarily be circumvented simply by pouring more maintenance men into the troubled area until the failure is halted. In such a case, quality is maintained, at the expense of larger cost. In the local segment, however, it may not be possible to maintain quality at any cost.

Discussion

One of the steps involved in ensuring that the maintenance design will indeed yield an operational system of the required overall reliability, is a demonstration that the maintenance technicians can work with the equipment to be maintained in such a way that the required probabilities of function output are achieved. This demonstration falls within the province of the activity which recommends the human engineering of the maintenance interfaces (activity F-9). Not only is F-9 responsible for demonstrating that the maintenance technicians are able to relate properly with the equipment to be maintained, but it must also make the actual provisions for equipment design to ensure that this occurs. These provisions actually form a part of the maintenance design of F-12. Without them, the design state at F-12 is incomplete, and the total design solution which is supposed to be ready at this time is not finished.

XI. TECHNICAL MANAGEMENT OF CREW PACKAGE DEVELOPMENT

Activity Group Requirements and General Considerations

The crew package is one of the end products of a system development cycle, and would be developed along with other end products. The crew package consists of trained personnel, of job aids, and of materials for use on the job to maintain human performance. When a crew package is produced as an end product, it is because a set of man performance capabilities is required for the operation and maintenance of the system. The ultimate evaluation of the crew package is thus made in terms of operational system performance.

A candidate for membership in an aerospace system crew comes to the development cycle for training in a "prepackaged" form. This unique feature of man requires that he be given unique treatment. Unlike a hardware item purchased from a vendor in packaged form, man is not amenable to repackaging. Because a prepackaged man has the capability to implement a variety of functions, once it is determined that he will be employed as a system means, a full complement of functions is allocated to him to make full use of his capabilities. The result of this allocation of function process is that a man may be assigned a wide variety of differing tasks. But prepackaged man is not compartmentalized in such a manner that his capability to perform one thing is unaffected by his capability to perform another. Therefore, there is need to attend carefully when allocating functions to a crew member to assure that conflicting performances will not be assigned to him. Care must be taken to avoid the assignment of two conflicting tasks that must be performed at the same time, and care must be taken to avoid the assignment of tasks that will give rise to internal conflict because of the noncompartmentalized nature of man.

In this chapter, we are concerned with those activities which provide the technical management necessary for the fabrication (training) and delivery of crew members as means in an operational aerospace system. The technical management that is needed must recognize that each crew member comes as a prepackaged unit and that he must be trained and utilized as a prepackaged unit without compartments. The end product of the activity group, the crew package, includes three classes of end products of the development cycle: trained crew members, job aids, and materials for use on the job to maintain human performance.

The technical management activities to be discussed in this chapter undertake first the task of defining the job makeup of each crew member. These technical management activities then oversee the production of training materials, of selection procedures, of job aids, and of the materials necessary to maintain crew performance on the job. These technical management activities also oversee the training of the crew members and the development of data to demonstrate that the crew package meets the requirements imposed upon it. These technical management activities do not include management of personnel support systems development.

The crew package development activities may be seen conceptually as a splinter group of the personnel products technical management activities discussed in Chapter V. The first activity in the crew package group appears in Function G of the development cycle model. Previous related activities have been encompassed by the personnel products technical management activities. In Function G, however, there is need to stabilize the job makeup for each crew member, and to determine how the performance capabilities assigned to each crew member will be obtained. These decisions require a unique focus upon crew members as individuals and, therefore, calls for a specific effort to integrate the crew package <u>within</u> the integrative efforts of personnel products development. The activities which are the topic of this chapter are designed to fulfill this need. The integration of the crew packages as a whole and of the personnel support systems remains the responsibility of the personnel products activity group.

There is justification for crew package management from yet another point of view. The job performance capability of any crew member will ordinarily be promoted by the use of three techniques which must complement each other so that the total job performance capability of each crew member is fully accounted for. The three techniques are: (1) crew member selection, (2) training, and (3) support of job performance by means of job aids. The activities in the crew package group provide for the integration of the separate activities concerned with these three techniques so that the activities will complement each other and yet be matched to the needs for each individual crew member.

Relationship of the Group to the Development Cycle Model

This activity group includes eight activities, two pairs in the line of development of the remote segment, and two pairs in the line of development of the local segment. Activity pairs (G-5, G-17) and (H-5, H-13) provide respectively technical management of the development of fabrication models and tools, and technical management of crew training (fabrication) for the remote segment. Activity pairs (G-6, G-18) and (H-6, H-14) are concerned in a similar manner in the development of the local segment.

The activities in this group relate to the technical management of personnel products development in roughly the same manner as the latter group relates to activities D-4 and D-7. Thus, the activities of concern here are an outgrowth of the activities concerned with technical management of all personnel products. The genesis of the activity group under discussion here is found in the technical management activities in Functions E and F.

The crew package for the remote segment includes all of the personnel products of the development cycle except the Safety and Support System. The crew package for the local segment includes all of the personnel products except the Human Support System. Thus, a crew package includes trained crew members capable of operator and maintenance technician performance, job aids, and materials for maintaining operator and maintenance technician performance on the job.[1] The crew packages delivered as outputs of activities

[1] Man-machine interface problems are considered in Functions E and F, and the solutions are therefore not in the crew package.

H-13 and H-14 also include supporting data which demonstrate that the crew packages satisfy the requirements for them.

In Function G, crew package management encompasses the fabrication of job aids, the fabrication of training materials and other training accoutrements, the preparation of fabrication models for materials to use on the job to maintain human performance, and instruments for selecting trainees. This list encompasses all of the "production" activities in Function G concerned with personnel products except for those concerned with the development of fabrication models for personnel support systems. In Function H, the crew package technical management activities embrace the training of personnel and the fabrication of materials for maintaining human performance on the job. Again, the only activities not included are those concerned with the personnel support systems.

Activities G-5 and G-6, which are the first activities in the group, include the allocation of job performances to crew members as a basis for the preparation of requirements for job aids, training materials, and the like. Activities G-17 and G-18 are concerned with the evaluation and integration of the crew products prepared in Function G. Activities H-5 and H-6 include the selection of candidates for training, the selection and training of instructors, and the specification of requirements for training in Function H. Activities H-13 and H-14 evaluate the delivered crew packages independently of the personnel support systems and develop data to show the "goodness" of the packages. The remaining activities in Function H include follow-up evaluations at increasing levels of integration of the system until in activity H-20 the entire installed system is evaluated and demonstrated.

Resources Needed

Inasmuch as this technical management group is an outgrowth of the activity group concerned with technical management of all personnel products, it is not surprising that many of the requirements for personnel resources are similar to those for the parent activity group. Technical management, as it is conceived here, includes not only the determination of what must be done by the activities managed, but also includes the monitoring of those activities and providing technical support whenever corrective action is necessary. Technical management also includes the evaluation and integration of the end products of the activities managed. To determine the skills necessary to discharge these responsibilities requires consideration of the activities to be managed. These include activities concerned with job aids, with training, with personnel selection, and with the preparation of material for maintaining human performance on the job. It also includes instructor selection and training and training program development. It follows that the manning of the activities in the crew package group must include specialists who have experience and up-to-date knowledge of the state of the art in each of these areas. In addition, specialist skills are required in the allocation of tasks to crew members in activities G-5 and G-6. For a crew size greater than two or three, computer assistance in fitting job assignments within tight constraints may be required.

The activities in the group which are concerned with evaluation (G-17, G-18, H-13, H-14) require for their implementation personnel skilled in the development of test procedures and in the analysis of test results. Mock-ups, simulators, and the like will often have to be fabricated for implementation of testing.

Special Note

As in the case of the technical management activities for the personnel products package, an exhaustive description of the inputs and outputs of the eight activities in the crew package group would be highly redundant, for these activities repetitively implement a basic technical management principle. That principle is discussed in Chapter V. The reader is referred to that chapter for a discussion of the phi function concept and the concept of specification of activity outputs in terms of the test by which they will be evaluated. Suffice it to say here that these concepts are assumed as being central to the technical management concept.

The activities in this group fall into four natural pairs, the first of each pair being concerned primarily with specification of design or fabrication activities, and the second being concerned with integration of the outputs of design or fabrication activities. However, some requirements for design and fabrication are placed on the technical management activities themselves; these will be discussed in what follows.

Development of Fabrication Models and Tools for the Crew Package Activities G-5 and G-17 (Remote)

Activity G-5 initiates the crew package design and fabrication activities in Function G. The four activities which are initiated must, however, be complementary to each other such that they comprehend completely the capability and performance reliability required of each crew member. Thus, activities G-8, G-10, and G-11 are concerned respectively with job aids, training, and selection of crew members. Because these three methods taken together must account for the total performance capability of each crew member, technical management is required to preclude unwanted overlap and to preclude gaps in coverage of the tasks assigned to each crew member. Taken together, these three activities provide for the basic capability of each crew member but activity G-9 must be taken into account in order fully to provide for the reliable performance of each function allocated for crew performance. Technical management of the entire set of activities is required to ensure that overall reliability objectives are achieved. It is therefore the task in G-5 to establish requirements for activities G-8 through G-11, such that capability and reliability requirements will be met for each crew member.

Previous to the initiation of G-5, no activity will have concerned itself with the stabilization of the job makeup for each crew member. The achievement of stabilization is not possible prior to Function G, simply because all of the data required for stabilization will not have been accumulated. Before the orders which are the outputs of activity G-5 can be prepared, the job makeup for each crew member must be identified. Therefore, an early task in activity G-5 will be finally to allocate operator and maintenance technician performances to specific crew positions. This must be done taking into account selection, training, and performance burdens which are imposed on crew members as the result of alternative ways of making up positions. What is desired is that the problems of selection, training, and job-aiding and the problems of performance reliability be minimized to the greatest extent possible by means of exercising choice in the allocation of tasks to crew members.

One of the activities which follows G-5 (G-8) is concerned with the fabrication of an end product of the development cycle. Therefore, G-5 must include the preparation of detailed descriptions of the manner in which the job aids will be evaluated as part of the overall evaluation of the delivered aerospace system. The evaluation method must be prepared in concert with early plans for overall system development at the system level.

Although the "GO" model does not indicate one, it must be assumed that activities G-5 and G-9 will be bridged by a phi function that will oversee activities G-8, 9, 10, and 11, for the purpose of ensuring that their end products will be delivered on time and that they will be satisfactory. This means that interim products of these four activities must be evaluated on a regular basis, and that schedules must be followed closely, probably with the use of PERT techniques. It also means that there must be the capability to determine and provide for corrective action when one of the monitored activities demonstrates incipient failure. Given an adequate implementation of a phi function, the business of activity G-17 is relatively straightforward. Activity G-17 in this case will undertake to integrate the end products of G-8 through G-11, to test the integrated end products, to make modifications as required, and to deliver a complete crew package at the level of development required in Function G.

Activities G-6 and G-18 (Local)

Activity G-6 does for the development of the local segment what activity G-5 does for the remote. It provides for the makeup of jobs for crew members and it develops the requirement statements for selection, training, job-aiding, and performance maintenance activities which follow it (G-12 through G-15).

In the case of activity G-6, however, the makeup task is a much more taxing one than is the similar task for the remote segment. In the case of the local segment, the makeup of jobs for crew members must be done within a specific crew size. Provisions for redundant personnel when needed and for the full use of available time without conflicting demands introduce additional difficulties into the process of making up the list of tasks that will constitute a job for any crew member. Especially is this a complex process in the case of those aerospace systems where man must operate as a crew member on a 24-hour per day basis over a period of a day or more.

Activities G-14 and G-15, which are follow-on activities to G-6, are concerned with end products of the development cycle, job aids, and materials for use on the job to maintain human performance. Therefore, weight, power, and volume constraints must be placed upon these activities and this, too, must be accomplished by activity G-6.

Activity G-18 is analogous to G-17. It is concerned, however, with the evaluation of personnel products for the local segment.

Crew Package Fabrication (Training)
Activities H-5 and H-13 (Remote)
Activities H-6 and H-14 (Local)

Activity H-5 is the lead technical management activity for the crew package for the remote segment, and H-6 is the lead activity for the local segment. We will discuss these two activities simultaneously. Basically, they must provide the orders to initiate and guide the training activities H-8 and H-10, and the activities concerned with the fabrication of materials for maintaining human performance on the job, H-9 and H-11. The specifications must, of course, include identification of the manner in which the outputs of these follow-on activities will be evaluated. H-5 and H-6, however, have two other objectives, which are not technical management. These activities, as shown in the model, also select the candidates for training employing the selection materials developed in Function G, and they select and train instructors employing the materials developed in Function G. An alternative to considering these functions as part of the crew package technical management group would be to call them out as separate activities under the control of the crew package activities H-5 and H-6. However, inasmuch as the implementation of these functions is fully provided for by the material prepared in Function G, such a callout would add further detail to the model simply for the purpose of identifying two rather straightforward types of activities.

It should be assumed that a phi function must be employed to cover the hiatus between H-5 and H-13, and that another must be employed to cover the hiatus between H-6 and H-14. If this is assumed, H-13 and H-14 are primarily evaluation and integration activities. However, the evaluation and integration that is performed in these functions is of signal importance, for it is the first step toward the installation and delivery of the complete operational system that is the output of the development cycle. Thus, H-13 integrates and demonstrates the remote crew package as a total package and must provide for the correction of any deficiency detected in the evaluation. Similarly, H-14 integrates and demonstrates the crew package for the local segment. The demonstration of the crew package is made under ideal environmental conditions, however. Joint testing of the crew package and the Human Support System is not attempted until activity H-16.

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XII. THE DEVELOPMENT OF INSTRUMENTS FOR SELECTING TRAINEES

Activity Group Requirements and General Considerations

The purpose of this activity is to prepare the selection instruments needed to choose the personnel who will be processed through the training program in Function H of the model. The training program must provide these chosen personnel with the human performance capabilities needed in the operational system. Furthermore, the training program should accomplish this task on time and within allocated resources. Therefore, the selection instruments must be capable of identifying those people who _can_ be trained quickly and easily to perform their assigned jobs.

Selection instruments are also used to identify candidates for training who have certain job performance capabilities already in their repertoire. The selection of candidates who have _some_ of the capabilities required on the job reduces requirements for training so long as all selected candidates have the same basic repertoire. Such capabilities are different than those capabilities which are _not_ job performance capabilities but which instead provide the base upon which training builds.

A third requirement for selection instruments derives from consideration of the personnel support systems. In general, the problems of devising a personnel support system for the flight segment of an aerospace system become insurmountable if the crew members to be supported suffer at the start from bad health. To preclude placing unduly severe requirements upon the personnel support system, personnel selection must be responsive to reasonable demands by designers for crew members with certain physiological and anthropometric characteristics.

The extent to which selection instruments are capable of meeting the three needs identified above, is a measure of their goodness. Notice that it was _not_ said that the goodness of the selection instruments is measured by how similar the basic performance capabilities of the chosen personnel are to those performance capabilities with which they will be provided by the training program. Indeed, it is sometimes advisable to steer clear of people who have similar capabilities to those needed, but not quite what is needed. As an example, the Air Force has found in their flight training programs that those people who have learned to fly on their own prior to joining the Air Force are usually more difficult to train than those people who have done no previous flying. The point is that the only correct measure of the goodness of the personnel chosen for training is the extent to which the capabilities they start with form a basis for a low-cost, timely, and effective training program and Human Support System. No other measure is appropriate.

Selection instruments are usually tests of one sort or another. The scores achieved on such tests, of course, are intended to represent the candidate trainees' basic performance capabilities, potentials, and health. Kinds of tests which are often central to trainee selection are:

1. Age, weight and physical stature tests;
2. Physical health tests;
3. Mental and emotional health tests;
4. Tests of technical training;
5. Basic capability tests.

Of the three methods of obtaining human performance capabilities which are built into the development cycle model (training, job aids, and selection), the most expensive is usually training. Training can be expensive in terms of time as well as in terms of dollars. Selection and training are complementary ways of achieving performance. Once it is determined what performance is desired of man, one must ask how such a man can be provided. If a man can be found who has all of the necessary attributes, then training is unnecessary. However, for aerospace systems it is unlikely that individuals with the necessary skills and experience can be found. If they could be found, it would be through the use of a selection device.

This activity has the potential for a considerable effect on the quality of the operational system and the cost and probability of success of the development cycle. If the activity is properly carried out, then men can be selected who will complete the training program within costs, in the time allotted, and who will have those performance capabilities needed in the operational system. On the other hand, if the selection instruments make a bad choice of trainees, then either the costs of training will increase, the time for training will increase, or some performance capabilities will be missing in the final crew. In such a case as this when the selection instruments have not done their job, several obvious things can sometimes be done to regain the performance capabilities that are in danger of being lost.

1. Revise the selection instruments and reselect;
2. Revise the training program to accommodate the individuals selected;
3. Prolong the training of the individuals selected.

Sometimes it may even be more advantageous to suffer the performance loss and the resulting lower operational system quality than to revise selection or training. The choice among these alternatives would be made in terms of the most desirable trades between cost, quality, and probability of development success.

To avoid a catastrophic failure of the selection instruments, it is desirable to build a test of the adequacy of the instruments into their development program. The difficulty in so doing arises from the difficulties in providing a practical criterion for measuring the success or failure of the test itself.

Relationship of the Activity Group to the Development Cycle Model

Instruments for selecting men to be trained as crew members of the operational system are produced in activity G-11 for the remote crew, and in G-12 for the local crew. Consideration of the crew selection problem begins long before Function G, however. In activities D-4 and D-7 selection problems are anticipated in order to develop confidence that the recommended allocations of operator performance and crew size may be stabilized. Subsequent activities in Functions E and F develop further information bearing upon the problem of trainee selection. The relationships among activities in the line of development concerned with the local segment crew selection is shown in Figure 13. The discussion which follows will describe the sequence of events depicted in this figure. In examining the figure, it should be kept in mind that formal rules for the development of functional designs have been violated in the interest of showing a concise picture of the relationships. Technical management activities, for example, are ignored. A similar diagram could be drawn for the sequence of activities concerned with developing selection instruments for the remote crew.

It can be seen from examination of Figure 13 that at least six activities are concerned with the development of requirements for human performance in the local segment. These are activities D-7, E-9, E-10, E-12, F-8, and F-10. Taken together, these activities identify all of the operator and maintenance technician performance required in the local segment of the operational aerospace system and in the Human Support System. In each of these activities it is necessary to look ahead at the selection problems engendered by the recommendations made in their outputs. This looking ahead is required to preclude the generation of an unsolvable selection problem. Each time there is a "look ahead," information previously developed with respect to the selection problem must be considered and new and more detailed information must be developed. In this manner, through Functions D, E, and F there will accumulate a fair amount of information about the selection problem and ways in which it may be solved. This accumulation of information will be available in Function G, but it will be used in G primarily as background information. It will not constrain selection activities in Function G to the use of solutions previously identified in the earlier functions.

In Function G, activity G-6 will employ the accumulated data with respect to the selection problem as one important data base for the identification of the specific job performances that will be assigned to each crew member and for the identification of the manner in which each job performance capability will be obtained — that is, by selection, training, or job-aiding. In the output of activity G-6, the job performances to be carried out by each crew member will be identified in detail with specific criteria for evaluating each job

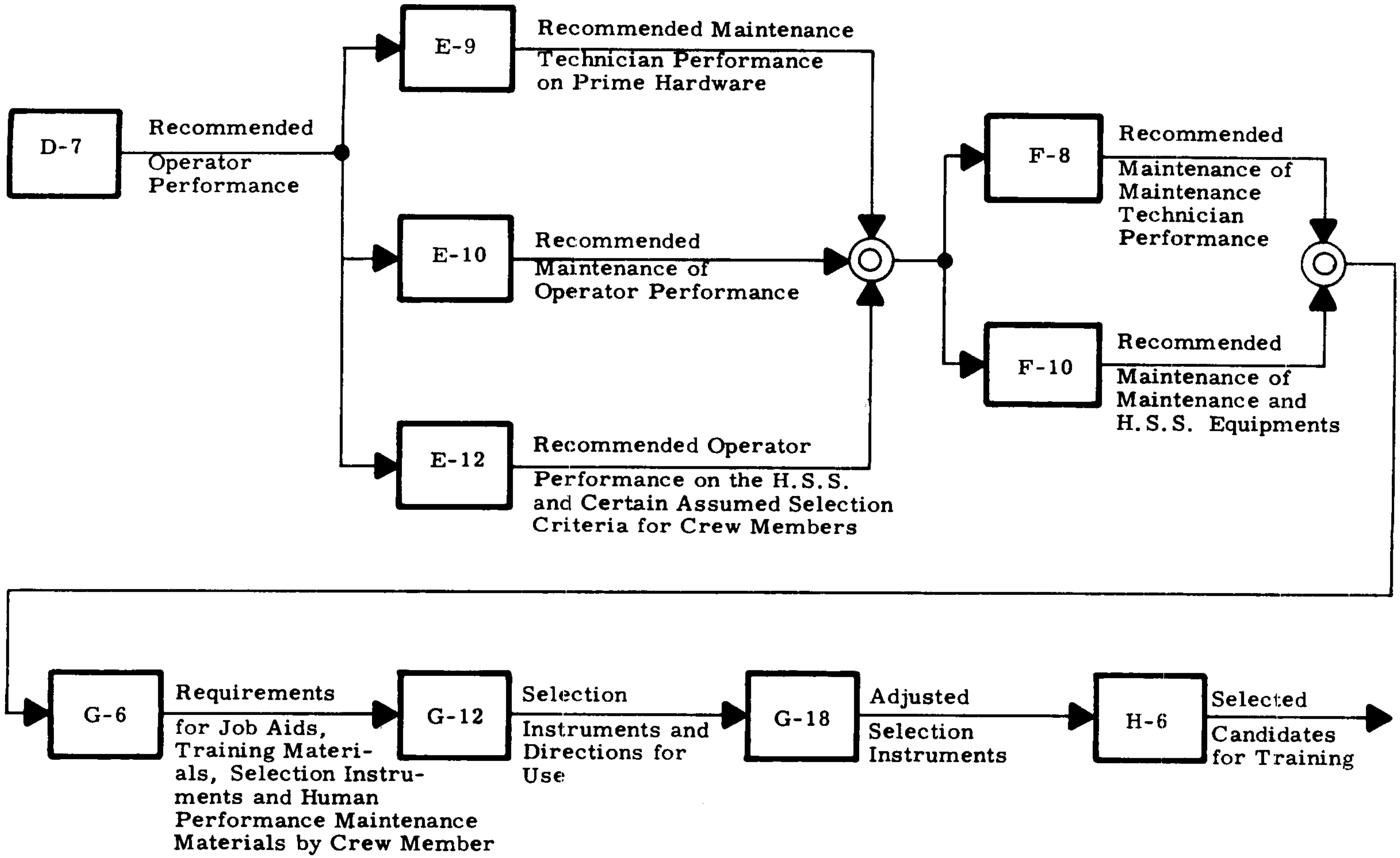


Figure 13. Non-standard array of activities in the line of development of selection instruments for the local segment.

performance. The output of G-6 will also identify for each crew member those job performance capabilities that must be obtained by means of selection. This will be an input directly relevant to G-12, where training instruments are produced. In order to arrive at a firm decision with respect to training and job-aiding, it will have been necessary in G-6 to estimate the cost of training and job-aiding. To estimate such costs, it will have been necessary to have made assumptions even previously about the initial repertoire of candidate crew members, for the initial repertoire will have an important influence on the necessary length of training and job aid complexity. The final determination of what will be trained and job-aided will therefore be accompanied by requirements for selection in terms of an initial non-job repertoire for each crew member.

It was earlier noted that selection must take into account not only the initial repertoire of non-job capabilities and certain job capabilities, but also physiological, psychological, and anthropometric characteristics which must be satisfied in order to minimize the problems associated with Human Support System development. It can be seen in Figure 13 that assumed criteria of this type are introduced into the flow of activities in the output of activity E-12. The assumptions, as corrected in the course of intervening activities, will be presented to activity G-12 in the output of G-6.

In response to the requirements of activity G-6, G-12 will produce selection instruments for the local crew. These will be adjusted and integrated with the outputs of G-13, G-14, and G-15 in the crew package activity G-18. The selection instruments will be employed in activity H-6 to select the crew members to be trained in activity H-10.

Resources Needed

Within psychology there is a well-developed subdiscipline concerned with problems of personnel selection. Professionals in this subdiscipline should always be employed for the purpose of developing selection instruments in the course of aerospace system development. To do otherwise, is to ignore an enormous body of carefully developed scientific information germane to personnel selection.

The specific personnel employed in activities G-11 and G-12 should probably be brought into the development cycle much earlier. Ideally, key specialists in personnel selection would assist in activities D-4 and D-7 and in all of the subsequent activities related to the identification of crew performance in Functions E and F. (See Figure 13.) Certainly, the key selection specialists must participate in activities G-5 and G-6 where the requirements for activities G-11 and G-12 are prepared. To prepare the requirements for G-11 and G-12 requires capability to anticipate whether or not requirements are possible to satisfy, and thus requires complete information about the state of the art of personnel selection.

Ordinarily, the specialists who implement activities G-11 and G-12 will not require complex equipments for the preparation of the selection instruments. Where equipments are required, simple devices will ordinarily suffice. However, in order to evaluate the selection instruments produced, it will be necessary to employ "subjects" representative of the population of candidates for crew training, and it may be necessary to employ simulators and mock-ups in test situations similar to the test situations necessary for evaluating job aids and trainees.

The Development and Fabrication of Instruments for Selecting Trainees Activity G-11 (Remote)

This activity is concerned with trainee selection for the remote crew. Its output will be the instruments for selecting candidates for training. The output package must include instructions for use of the instruments and data to demonstrate that the selection instruments are satisfactory. The input to G-11 will derive from G-5, a crew package technical management activity. The input will identify the job performances that must be in the repertoire of selected candidates, requirements for general aptitude and background capabilities, and for physiological and psychological attributes.

Activity G-12 (Local)

Like activity G-11 this activity is concerned with trainee selection. The output includes everything necessary to carry out the process of selecting candidates for training for the local crew. The package of materials will thus include selection instruments and instructions for their use. The output should also include data to demonstrate that the selection instruments achieve their objectives when used as directed. The input to G-12 derives from G-6. It is similar to the input to G-11 which derives from G-5.

Discussion

Of all of the activities related to personnel products in an aerospace system development cycle, those concerned with personnel selection probably rest upon the most extensive base of scientific information and professional practice. The armed services, including especially the old Army Air Corps, early recognized the importance of personnel selection. In the case of the Air Corps and, later, the Air Force, there was significant payoff from the very beginning when scientific selection procedures were employed for the purpose of identifying promising candidates for aerospace system training. As one result of this recognized payoff, research and development of selection procedures for aerospace crews has been well supported for over two decades. It would be inappropriate here to attempt to encapsulate the extensive literature that has been developed in this area.

What will be useful here is a discussion of the special way in which selection of crew members is determined by the three principal facts of the requirement statement which initiates activity G-11 or G-12. One of these is a requirement that personnel be selected on the basis of mental health, physical health, and anthropometric characteristics such that the design of an effective Human Support System is not made unduly difficult. The problems associated with Human Support System design are specifically discussed in Chapter IX. In that chapter, the Human Support System is defined as a system which provides <u>conditions</u> such that there is no unexpected loss of reliability of human performance because of degraded environmental conditions. Thus, it is recognized that reliability predictions for the performance of specific tasks by humans are valid only when certain (stated) environmental conditions obtain. (The expected reliability of a resistor is degraded under very high temperature conditions; so is the expected reliability of a man performing a specific task.) A second objective of the Human Support System is to provide for the long-term health and sanity of crew members. Thus, society demands that the well-being of aerospace crew members be preserved outside of the job situation. When we are concerned with sustaining reliable performance we are, of course, concerned with reliable performance inside the job situation.

To meet the objectives of the Human Support System; we must commonly provide for temperature control, noise control, vibration control, and so on. We must also often provide for nutrition, breathing atmosphere, waste management, water management, and so on. Thus, the concept of a Human Support System encompasses environmental control systems and life support systems. But it encompasses more. It includes also providing for rest and recreation, for personal hygiene, for physiological and psychological monitoring, and for physical and mental health maintenance. It can be seen, then, that the problems of designing an effective Human Support System may be greatly increased if support must be provided for personnel with degraded physical health or for persons with degraded mental health. It can also be seen that the provisioning of sleeping space, of nutritional supplies, of activity areas, and so on can be complicated if crew members of unusual anthropometric dimensions are accepted. What is necessary is that explicit assumptions be made in designing the Human Support System with respect to the basic physiological, psychological, and anthropometric characteristics of the crew members to be supported. These assumptions may be stated, for example, in terms of probability of cardiovascular disease leading to disability to perform, probability of behavioral maladjustment leading to performance degradation, and maximum daily caloric intake. On the other hand, requirements may be stated in terms of the measurements to be taken and the scores to be achieved to certify a candidate as free from cardiovascular disease, in terms of the tests and test scores by which freedom from mental illness may be certified, and in terms of body dimensions. In the case of either set of examples, a basis is provided for stating criteria by which candidates should be selected for training. In the former case, a good deal of translation is required before practical selection instruments and selection criteria may be set down, whereas in the latter case relatively little work needs to be done to achieve practical selection instruments. It is not of great importance where the translation is done, whether in association with Human Support System development or in activities G-11 and G-12. What is important is that the selection criteria which derive from consideration of the Human Support System be justifiable in terms of the effects to be achieved upon Human Support System design and operation. Arbitrary selection requirements for trainees in "good" mental and physical health and of "normal" body dimensions should not be employed simply because "it is better to have a man of good health than a man of poor health." While such generalizations may be true, the effort which can be justified in selecting a man of good health cannot be determined on the basis of such a homespun rationale. If the general assertion is true, the reason for it can be found, and if the reason for it is stated explicitly then there is a basis for deciding when selection criteria are appropriate. There is then also a basis for determining what proportion of system development resources to expend for the purpose of carrying out the selection process.

A similar argument for relating selection criteria to specific effects in terms of elements of system quality and cost can be made in the case of requirements for selection on the basis of job performance capability. Selection of crew members who can already perform some of the tasks specified in their job descriptions is a legitimate way to reduce training time and training cost. Selection for such capabilities is quite straightforward. What is required is that the needed job performance capability be identified in terms of the way in which performance will be evaluated. Selection is accomplished then simply by applying the specified evaluation tests. To avoid the commonest of errors in this regard, it is necessary that the manner of testing and the target test scores be derived explicitly and systematically in the activities which precede G-11 and G-12 and which are focused upon identifying the operator and maintenance technician tasks to be carried out by crew members in the operational situation. It is desired that the original specification of the tasks to be allocated to crew members be in terms of the output states to be achieved by human performance and in terms of the input states to the human performance. Such specifications are a basis for evaluation and should be preserved and employed without unnecessary compromise in the preparation of that part of the selection instrument for a crew member which is designed to test him for specific job performance capabilities.

The third part of the requirement statement for the development of selection instruments is concerned with avoiding undue training cost which would result if the initial repertoire of the trainees were too elementary, or if the basic learning capability of the trainees were too poor. The manner of selecting for the initial repertoire is essentially to test for specified performance capabilities by performance tests. The performance capabilities of interest will be those it is wished to assume in the preparation of the training materials. In general, when trainees are selected for an initial repertoire of performance which minimizes training requirements, difficulty in finding appropriate candidates is increased. Therefore, there is a trade-off consideration in which it is desired to find an initial repertoire that will permit finding sufficient numbers of candidates and which will also avoid an unduly lengthy or costly training program.

It is the satisfaction of the requirement for "trainable" candidates that has been the subject of much research and controversy. What is needed is selection criteria that will sort out candidates who can most readily be trained reliably to carry out required operator and maintenance technician performances. For a specific aerospace system development cycle, the number of candidates to be selected typically will not be so great that extensive validation of highly sophisticated selection instruments for "trainability" can be justified — except in the case of widely used aircraft systems. Therefore, the greatest difficulty is associated with the development of selection criteria of this kind in which confidence can be placed. Reliance must be placed upon evidence developed in previous similar situations. In good part, the difficulty of developing the part of the total selection instrument package which deals with selection for "trainability" will be the most difficult when the system under consideration departs significantly from previous aerospace system concepts.

XIII. THE DESIGN AND FABRICATION OF JOB AIDS

Activity Group Requirements And General Considerations

Job aids are end products of a system development cycle; they are delivered and installed along with the other things which make up an operational system. When job aids appear as end products, it is because they are needed to foster operator and maintenance performance in the operational situation. Thus the key requirement for job aids is stated in job performance terms, and job aids are ultimately evaluated by determining whether or not they do indeed support job performance with the required reliability.

An example of a job aid is a troubleshooting chart for a piece of hardware. If a crew member is required to have the capability of repairing a piece of hardware, it may be both cheaper and more reliable to use a troubleshooting chart to provide this capability rather than train it into his repertoire. A job aid can be a sheet of paper like the troubleshooting chart, it can be a technical manual, or it can be a complicated audiovisual device. But whatever form a job aid takes, its purpose is to provide a particular performance capability to some crew member, and its goodness is judged by the extent to which it achieves this end.

Occasionally it is difficult to determine whether or not a given personnel product is a job, a tool, a piece of maintenance equipment, or even a product of the human engineering of a man-machine interface. It seems that no definition can be given for a job aid which clearly discriminates in all cases. In general, however, it is satisfactory to say that a job aid is any product of a system development cycle which provides the stimulus conditions necessary to guide required human performance in the job situation. Performance which is job-aided is complementary to performance in the learned repertoire of a crew member. Within the present state of the art it thus appears that there are only two ways to obtain job performance: (1) by using the learned repertoire, and (2) by providing stimulus materials for use on the job which have the capability of eliciting required job performance. Job aids may be prepared in a wide variety of formats. Printed job aids are frequently used. Audiovisual and computer-supported job aids are becoming more popular as equipment technology improves.

In the course of system development it must be decided what human performances necessary for system operation and maintenance will be job-aided, and which will be obtained by selection or training. Allocation is normally made on the basis of cost and quality considerations. When used judiciously, job aids can have quality and cost advantages. Thus, job aids may contribute to quality by ensuring reliability of performance where reliability cannot be assured by means of training. They may also permit the use of human performance where it would not otherwise be possible because of the limits of the learning capacity of crew members. For example, job aids may provide crew members with large stores of data which cannot be committed to memory but which must be employed to enable performance. In the development of job aids, the capabilities of the very best engineers and technicians may be utilized so that the resulting job aid can support high-level performance on the part of far less able personnel. On the cost side, job aids may have an advantage by virtue of the fact that the use of a job aid may significantly reduce training requirements. The use of job aids may also reduce requirements for materials to be produced to maintain human performance in the job situation. Where changes in the required performance of operators and maintenance technicians can be anticipated during the operational life of the system, the use of job aids may be preferred because of the ease and lower cost with which changes are made as compared with effecting changes in repertorial performance.

Job aids tend to be used heavily in support of maintenance performance because of the wide variety of maintenance performance capabilities that may be required of a maintenance technician, and because of the large amounts of data required to support maintenance performance. They are less often used to support operator performance because operator performance is more frequently time-constrained such that there is no time to refer to a job aid during the course of performance. In general, job aids have not been useful for supporting motor performance.

Job aids are important both in the remote segment and the local segment of an aerospace system. In the local segment they must be designed within weight, power, volume constraints which do not apply so strictly to the remote segment. They may be especially useful in the local segment as a way of extending the capabilities of a small crew. For lengthy excursions they may be useful to provide support for little used performance capabilities.

Relationship of the Group to the Development Cycle Model

There are two lines of development of job aids in the aerospace development cycle model: one for job aids to be used in the local segment, and one for job aids to be used in the remote segment. These lines of development do not, for the most part, interact with each other. Quite independent performance capabilities are required within the separate segments. Despite the fact that there will be very little interaction between these two lines of development, they are quite similar with respect to the internal sequence of events. In view of these similarities, we will discuss only the sequence of events related to the production of job aids to support performance in the local segment.

The only job-aid activity in the local segment which is explicitly called out on the development cycle model is box G-15. This box falls within that part of the development cycle where final preparation for fabrication takes place (Function G). Job aids are produced here, in advance of the main fabrication effort, because they are needed in the crew training program in Function H.

Although box G-15 is the only function in the model which explicitly refers to job aids, there are, in fact, many other activities which relate to job aid production. In the model, these other activities are primarily concerned with outputs which are not job aid outputs, however. The important activities in which job aid development takes place, outside of activity G-15, are identified in Figure 14. This figure traces the sequence of events from activity D-7, where job aids are first considered in Phase II, through Functions E and F to Function G and then through Function H. The information given in the figure emphasizes job-aid related attributes of the output states of the functions

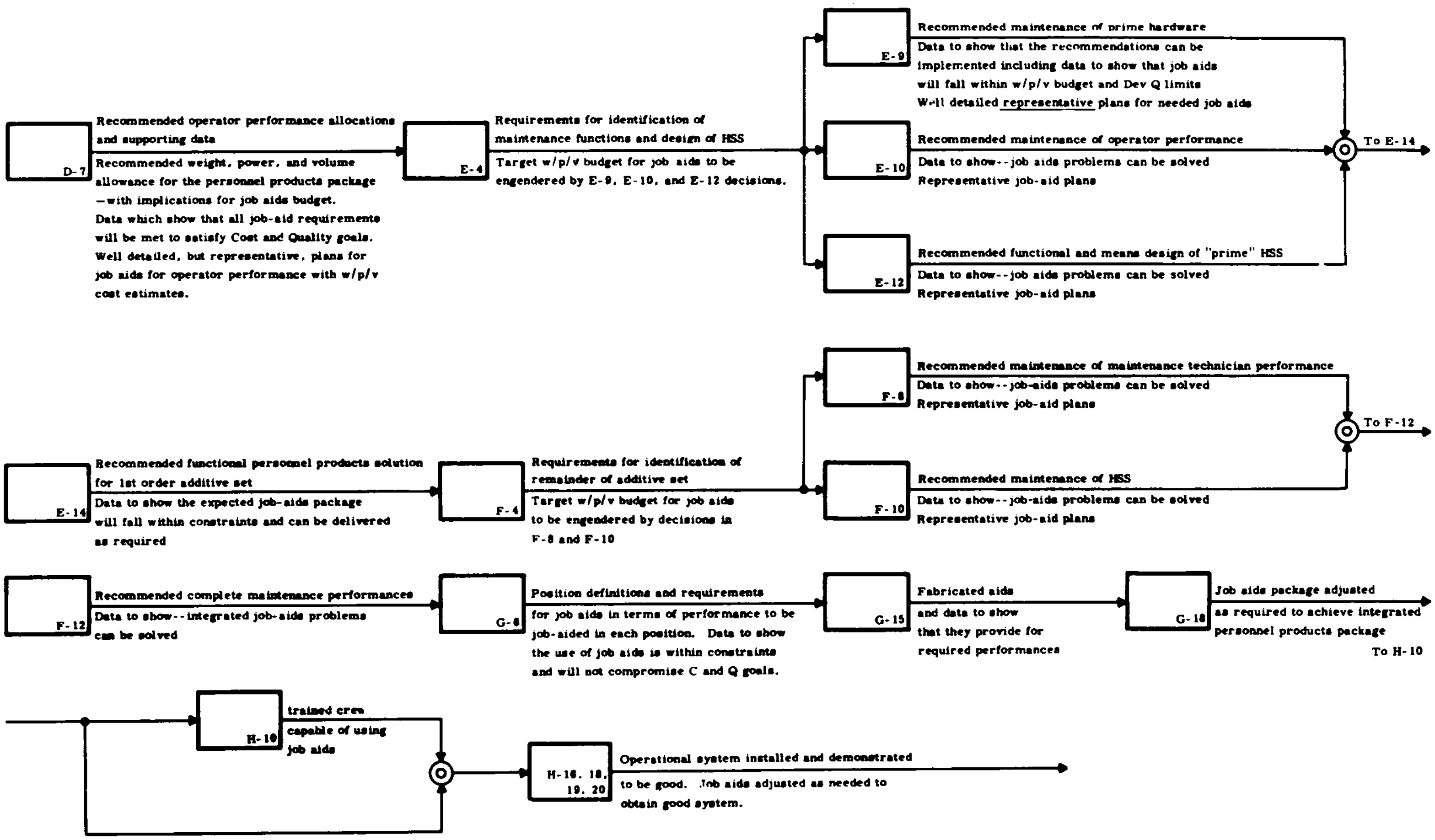


Figure 14. Overview of the Chain of Events which Leads up to Activity G-15 and of the Use of the Output of Activity G-15.

shown. Thus, the identification of the output states in the figure is not complete; it is biased to present important job aid information. In order to show the sequence of events related to job aid development with a minimum amount of clutter, the figure shows direct relationships between boxes which are not truly directly related. Thus, the figure shows the output of D-7 as an input to E-4, whereas in the overall model there are many intervening functions. To show the intervening functions in this figure would obscure the picture of job aid development that it is desired to present. It should be kept in mind that the figure violates the model but that it does so for good purposes.

As shown in the figure, job aid development in Phase II begins in activity D-7, where it must be shown that the recommended allocation of operator functions will not create design problems when activity G-15 is reached. In order to make this kind of demonstration, there must be fairly detailed prediction of the types of job aids that will be required to complete system design and fabrication. Prediction must be detailed enough, for example, to permit an estimate of weight, power, and volume allocations which should be made to allow for the job-aids part of the personnel products package. Consideration of job aids in activity D-7 thus encompasses all of the activities shown in the figure between D-7 and G-15. However, it does this in a predictive and representative manner, on the basis of less information and in less time than will be available for the accomplishment of the activities themselves.

In Function E, more detailed anticipatory study of the job aids required to support first-order maintenance performance will take place (activities E-9, E-10, and E-12). In each case, the job-aid planning that is done is for the purpose of generating confidence that it is safe to proceed with design. The planning is <u>not</u> for the purpose of constraining the decisions that will be made in activity G-15. Thus, in the figure it is noted that the job aid plans are representative. These activities, E-9, E-10, and E-12 are bounded by E-4 and E-14 where the personnel product package as a whole is considered. Activity E-4 sets forth requirements, and E-14 considers, among other things, the job aid implications for the personnel package as a whole.

In similar manner, activities F-8 and F-10 which are concerned with second-order and third-order maintenance are bounded by activities F-4 and

F-12. F-4 sets forth requirements and F-12 integrates the outputs of the intervening personnel package activities. F-8 and F-10 set forth representative plans for handling the job-aid problems engendered by second- and third-order maintenance considerations and demonstrate that the problems can be solved within constraints.

G-6, which immediately precedes G-15, plays a key role with respect to job aids design and fabrication. It is in G-6 that position definitions are finally stabilized and it is within G-6 that the determination is made for each position as to which elements of performance will be obtained by means of job-aiding, which by training, and which by selection. In order to make the trade-off among the job aid, selection, and training methods, Cost and Quality implications of alternative approaches must be made. To make such estimates requires capabilities and activities very similar to those that will be carried out in G-15. Thus, possible designs of physical job aids must be considered in G-6 and estimates must be made of the Quality and Cost implications of such representative job aids.

As shown in the figure, G-15 delivers job aids which will, in the real world of system development, be required to undergo several adjustments before they finally are delivered and installed as part of the operational system. The figure shows the key activities in which adjustments may take place. They are activity G-18 which is the personnel products package integration activity in Function G, H-10 where training involving the use of job aids may reveal shortcomings, and finally activities H-16, H-18, H-19, and H-20, which are concerned in sequence with the assembly, installation, and test, first of the remote segment and then of the total system.

Estimates of what is required to produce job aids for the remote segment (activity G-8) may also be made on the basis of the information presented below for activity G-15. Those differences between G-8 and G-15 which do present themselves are pointed out within the description of G-15.

Resources

The crew of personnel required to carry out the job-aids fabrication task (activity G-15) may begin to form very near the beginning of the design phase.

Thus, early in design, when the functional design of the prime system is undertaken, there will be need to foresee requirements for job aids. There will also be need to estimate weight, power, and volume requirements of job aids for the local segment, and to present data which show that the job aids problem that will be engendered by approval of the recommended functional design will be a solvable one (activity D-7). The job aids experts who assist in these projections would next be required to support decisions about the allocation of functions to maintenance technicians (activity E-9), to assist in the projection of methods for maintaining operator performance (activity E-10), and to project job-aid requirements for supporting operation and maintenance of the Human Support System (activity E-12). The number of experts required to support these activities would need to be greater than the number required during the initial considerations of job-aid requirements (Function D). In fact, the greatest use of job aids is ordinarily in support of maintenance technician performance, and in a typical aerospace development cycle, considerable effort would be required during the process of allocating maintenance technician performance (activity E-9) to anticipate the job-aid requirements thus generated. In the next stage of design (the final allocation of means, final interface design, and completion of the additive set), the anticipation of requirements for job aids is again of importance, especially for the purpose of supporting second- and third-order maintenance activities (activities F-8 and F-10). Thus, by the time activity G-15 is initiated, a core crew with experience in considering job aids will have been formed. This nucleus will have to be augmented to carry out design, fabrication, and evaluation in activity G-15, and, in practice, it will not be possible to dismiss the entire crew upon completion of activity G-15 because it can be anticipated that significant retrofitting and further development of job aids will be required throughout the process of system fabrication, installation, and evaluation. In fact, the crew retained throughout fabrication (Function H) for these purposes may be retained with little diminishment during the operational phase as well so that subsequent changes in the system during the operational phase may be reflected in corrected job aids.

The job aids personnel required in the initial personnel products crew during prime system design should include experts familiar with the variety of types of job aids that have been demonstrated to be useful and should include personnel capable of estimating the cost and time required to design, fabricate and deliver job aids of all types. The crew should also include personnel skilled in identifying the kinds of operator and maintenance performances which are best promoted by means of job aids. It is best if the personnel with this capability are also the specialists who are familiar with the state of the art of job aid techniques. When the design moves into concern with maintenance technician performance (Functions E and F), the specialist in the field of job-aiding maintenance performance will be required. This is not to suggest that such experts are not required earlier. Rather, it is to call attention to the fact that a proportionately large effort will be required in the job-aiding of maintenance performance as opposed to operator performances in most systems. When design and fabrication are undertaken, the job-aid crew must, of course, be expanded again (Function G) to include detailed design and fabrication technicians. Also, it will usually be desirable during this phase to employ the services of a model-shop crew in order that prototype job aids may be developed and evaluated prior to stabilization of design. During the retrofit phase the crew will consist mainly of technicians capable of adjusting or modifying existing job aids. Requirements for overall conceptual design and inventiveness will be reduced.

Prior to the fabrication phase, equipment to support job-aid activities (Functions D, E, and F), will usually be restricted to model shop facilities and modest graphic and reproduction support so that recommended new approaches to the solution of job-aid problems may be evaluated early enough to obtain data to support design recommendations. To support activity G-15, full-scale model shop, graphic arts, and printing facilities will be required. Electronics fabrication and computer programming capabilities will also very likely be required for complex aerospace systems. During retrofit activities facility support will be required for reprogramming of existing job aids.

Design and Fabrication of Job Aids
Activity G-8 (Remote)

The output of this activity is an end product of the development cycle. The output is all of the job aids necessary to support operator and maintenance technician performance in the remote segment. The output must include data which demonstrate that the job aids do indeed support the performances for which they were designed. The input to G-8 derives from G-5, a crew package technical management activity. The input will identify the job performances which must be supported by job aids, the crew members who will use the job aids, and any constraints within which the job aids must be designed and fabricated. These data will be the basis for evaluating the job aids, and they must therefore also identify the conditions under which the job aids will be employed in the operational situation.

Activity G-15 (Local)

The output of this activity is a complete set of job aids for use in the local segment. The output is thus an end product of the development cycle. Not only must the job aids be delivered, but also data which demonstrate that the job aids promote the operator maintenance technician performances they were designed to promote. The conditions under which the delivered job aids will be evaluated must be identified in the input to G-15, which derives from G-5. This input will contain all of the types of data contained in the input to G-8. It will also identify the weight, power, and volume constraints within which the fabricated job aids must fall.

Discussion

Job aids are produced for both local and remote segments, to support seven basic classes of performance. These basic performances are:

1. Operator performance;
2. Maintenance of operator performance;
3. Maintenance of prime equipment;
4. Maintenance of maintenance personnel performance;
5. Operation of the support systems;
6. Maintenance of the support systems;
7. Maintenance of maintenance means.

During activity G-6 (or G-5) all personnel performances are investigated to find the best way to ensure their implementation (i.e., through personnel selection, training, or job-aiding). Functions likely to be assigned to G-15 (or G-8) for job-aid development would, for example, be those which:

1. Involve a lengthy process of steps. The number of steps could be too great to rely on man's memory, especially if performed infrequently.

2. Involve a host of possible situations each requiring alternative actions.

3. Require job-aiding to ensure required reliability.

Job aids are sometimes needed for the beginning, middle, and terminal portions of functions. In other words, they can be used to:

1. Initiate a function only.

2. Provide guidance throughout the function.

3. Provide data for evaluating the output state of the function for accuracy or timeliness.

Clearly, combinations of these may also be used.

The level of detail of information content of the job aid may vary from a simple reminder to perform a task the person is <u>already</u> trained to do to a complete set of well-defined procedures, with supporting data, the performance of which requires little or no prior training.

Practically all of the various ways of developing job aids require that functions to be job-aided first be broken down into performance elements or steps. Then information needs are derived which are important to successfully carry out the steps. Following these comes a consideration of: media and packaging by which data should be presented, job-aid design, and, finally, the production, testing, and delivery of the aid itself.

Using these guidelines, a representative method of developing job aids is presented below. The adoption of a specific process for providing job aids must await the constraints of the particular system under development. Therefore, the method detailed below may not be universally applicable.

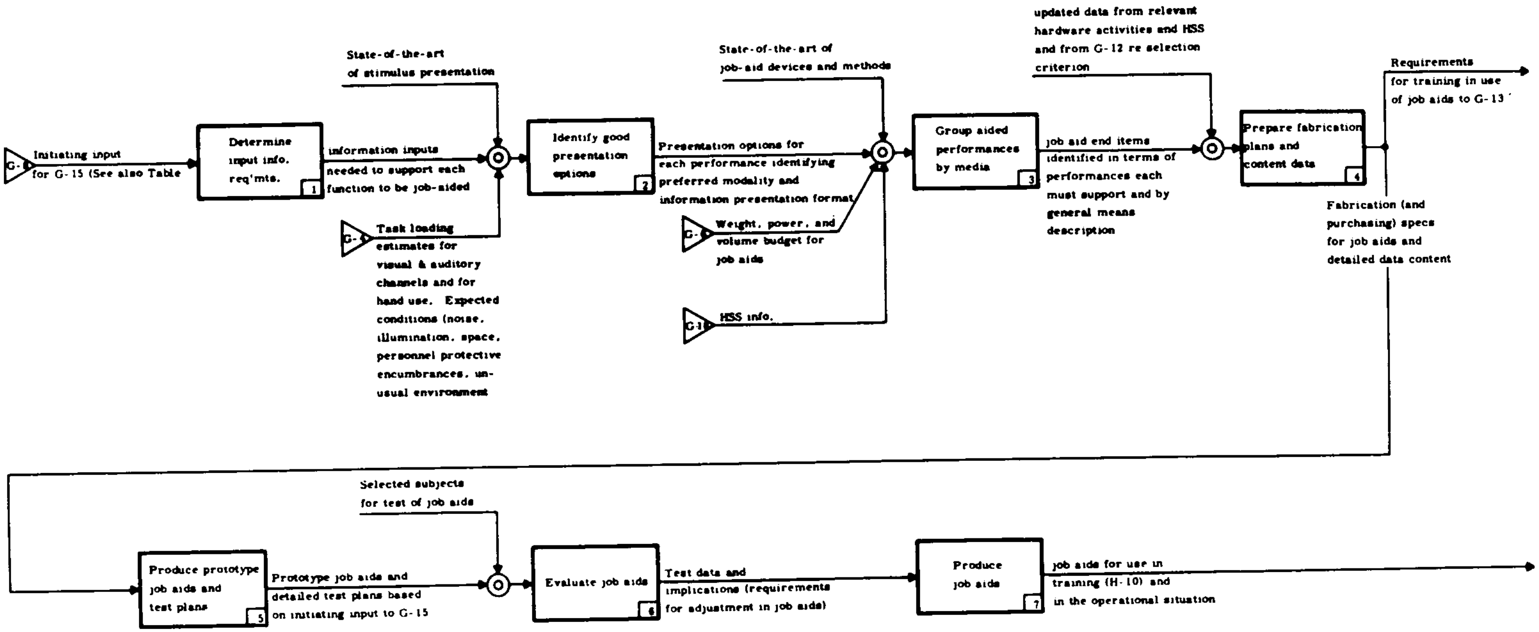
The description of the method is keyed to Figure 15. Each box in Figure 15 represents a component task of activity G-15. Inputs and outputs which occur between these tasks and other activities of the development cycle are shown to reflect overall interaction during the job-aid development. For simplicity of presentation, the detailed descriptions of inputs and outputs are explained in the text, while only "placeholders" for such are on the figure.

Since the same steps in the method would be necessary for both remote and local segment job aids, only one thread of development is shown rather than presenting one parallel process for each segment. The differences between segments will be reflected in the text.

In following the typical sequence of events within activity G-15, it must be remembered that there will be a crew integration activity in parallel. Thus, in the case of a real development cycle there would be transition activity between G-6 and G-18 that would oversee the integration of activities G-12, G-13, G-14, and G-15 and that would act to mediate among them in cases of conflict. In Figure 15, inputs from parallel system products and hardware activities are shown as well as outputs to parallel activities. Such inputs and outputs would, of course, be mediated by appropriate higher levels of segment and system integration.

The following is a representative approach to job-aid development.

Task 1. Determine input information requirements. —The purpose of the first task is to determine the information which must be provided by the job aids to the system personnel. The first step would be to break down the functions identified in the input from G-6 into performance elements. This breakdown need only be carried far enough to identify the specific data required by man to yield the output of each function assigned to him. Then the data needs would be documented for each step in the function.



NOTE: It should be assumed that once data are introduced into the sequence of functions (tasks) they will be available to all subsequent functions even though the inputs are not repeated in the figure.

Figure 15. Representative Component Functions of Activity G-15, Their Sequence, and Their Relationships to Adjacent System Development Activities.

In order to perform this function breakdown and information identification, several inputs are required. The inputs, their sources, and the reasons for their need are described in Table 5.

On the basis of the information analyses and the job requirements, decision should be made for each element of performance as to whether the performance will permit "shortcutting." A shortcut job aid is one which enables the user to deliver the output of his assigned function without going through all of the intermediate steps. For example, a summary table of the trouble locations within a piece of equipment with entry by malfunction indication shortcuts the performance of troubleshooting.

Task 2. Define content and modalities. — The objective of this task is to determine the content type of the information which should be presented to system personnel, and the sensory receptor(s) to which the information should be directed.

By "content type" is meant whether the data should be in the form of prose, procedures (step by step), tables, diagrams, pictures, symbols, or combinations. The concern for sensory receptors is with reference to whether man should receive the information using visual, aural, or tactile senses, or some combination of these.

There is an interaction between content and sense modality, and for this reason they are considered together. It is obvious that tables, diagrams and pictures must be presented via the visual mode. Prose and procedural information may be encoded for receipt by any one of the three modes.

The classification of information into content types should be fairly straightforward. Certain data, by their very nature, dictate the general format which is appropriate. For instance, a wiring diagram is a conventional device for identifying the location of wires, busses, etc. If maintenance personnel need such location data, then the wiring diagram as a content type would probably be very appropriate.

TABLE 5. INPUT REQUIREMENTS FOR TASK 1

	INPUT	SOURCE	USE
1.	Type of function (e.g., operator, maintenance of prime equipment, etc.)	Activity G-6	Allows grouping functions by type.
2.	Function identity symbol (e.g., No. 18)	Activity G-6	Purely for "keeping track" of function.
3.	Output of function (required state of things when function completed)	Activity G-6	Provides the requirement for job-aid development.
4.	Required probability that function output will be achieved each time performed.	Activity G-6	Qualifies the requirement for job aids.
5.	Acceptable tolerance within which output may vary as regards accuracy.	Activity G-6	Qualifies the requirement for job aids.
6.	Acceptable tolerance limits in terms of time taken to perform function.	Activity G-6	Qualifies the requirement for job aids.
7.	Frequency with which the function output must be realized per mission/ unit time/life of operational system.	Activity G-6	Qualifies the requirement for job aids.
8.	Input to functions in terms of data and physical conditions which initiate its performance	Activity G-6	Provides a "starting signal" to person and shows limits on his input information for beginning task.
9.	Person who is to perform function, and his position (title).	Activity G-6	Satisfies need to attach function breakdown to personnel by name or position.
10.	Description of hardware to level of detail depending on how it is interfaced with (e.g., operation or maintenance) in terms of controls, displays, access to and operation of.	Prime Equipment E-11, F-9	Allows expression of function breakdown since almost every step will refer to equipment man interfaces with.
11.	Description of tool (s) man will use to perform functions in terms of name and use.	E-11, F-9	As above, allows more information by which to express function breakdown.
12.	Description of function performed by person just before and immediately following the one to be job-aided.	G-6	Provides a perspective to Task 1 personnel by understanding the physical and mental "set" of the system personnel who will perform the aided task.

The end products of Task 2 will be a documented mating of content type and modality for each function or step within functions, as appropriate. Where clear preferences cannot be determined, alternatives should be given.

Task 3. Group-aided performances by media. —The purpose of Task 3 is to select job-aid media and job-aid end items. Representative media grouped by modality are illustrated in Table 6.

Up to this point, the performances to be job-aided will have been considered separately (except for estimates). The performances must next be grouped such that each group corresponds to a job-aid end item. It is the end items which use up the weight, power, and volume budgets and grouping must take the allocated budget into account. For the local segment, this will mean that care must be taken to consolidate performances in groups to minimize the number of job aids required.

Task 4. Prepare data and select job aids. —The type of presentation (i.e. content type), modality, medium, and end items for each aided function will have been chosen in earlier tasks. This task is devoted to the preparation of the data which the aid is to present and the selection of off-the-shelf aids where such exist. Detailed designs of special aids is also an output of Task 4.

Preparation of the text for the job aids is fairly straightforward but requires an exchange with G-12. Activity G-12 is concerned with the development of instruments for selecting trainees. On the one hand, trainees should be selected in order to minimize requirements for training in the use of job aids (e.g., many job aids cannot be employed with illiterate crew members). On the other hand, job aids must be developed with full recognition of the selected baseline repertoire of crew members. Virtually simultaneously, consideration must be given to training requirements which derive from the planned use of job aids. Whenever a job aid is introduced, trainees must ordinarily be taught when to use it and how to use it. Thus, among selection training and job aids, there is a continuing trade-off exercise so that none of the three becomes costly or difficult.

TABLE 6. REPRESENTATIVE TYPES OF JOB-AID MEDIA GROUPED BY MODALITY EMPLOYED

VISUAL	Displays Manuals and checklists Card file Opaque material and projector Transparencies and projector Slides (e.g., 35 mm, lantern) and projector Strip film and projector Motion pictures and projector TV receiver and video tape Computer printout Charts (e.g., flip, solid) Equipment plates
AUDITORY	Headphone/speaker and player (record, tape, etc.) Voice Audio portion of TV Audio portion of motion picture
TACTUAL	Vibratory devices

Table 7, below, exemplifies one way of presenting the output of Task 3. The information developed in Task 3 is presented in Columns 5, 6, and 7.

TABLE 7. REPRESENTATIVE FORMAT FOR TASK 3 OUTPUT

1	2	3	4	5	6	7
Function Identity	Function Type	Content Type	Modality	Alternative Media for Job Aids	Preferred Medium	End Item
No. 167	Operator	Procedure	Visual	(a) Face-plate (b) Check list	(a) Face-plate	Faceplate incorporating Function 173

A major difference between the remote and local segments with respect to job-aid treatment appears when actual job aids are selected and designed. The local segment will levy more stringent constraints on the allowable weight, power, and volume of the job-aid package. Of course, both segments will enforce a dollar budget constraint for development costs.

Task 5. Produce prototype aids, test plans. —The output of Task 5 will be a prototype set of all job aids and plans for testing them.

Using the output of Task 4, prototypes will be procured from manufacturers for use as is, or procured and modified to meet specifications; manufactured from design using standard parts; produced, if software, as prototype copy.

On the basis of G-6 inputs, plans will be produced for experimentally testing the capabilities of job aids to achieve the required output states of functions within desired accuracy and time limits. Experiments must be carefully designed to allow conclusions to be made with high confidence that the prototype aids meet all job-support specifications or that they do not.

An input is necessary from G-12—the updated personnel selection criteria to be used. This will allow provisions in the plan for choosing subjects to test the utility of job aids. Other inputs are needed from G-13—descriptions of the training equipment and facilities which will be available. The experimental design should specify the results required, the detailed procedures to be used for carrying out the experiments, the technique for evaluating the results, and the facilities needed. The data package to be developed by testing and which accompanies the job aids as a companion end product of activity G-15, will contain the results of the experimentation as evidence that job aids will satisfy the performance requirements.

Therefore, Task 6 will receive as input the prototype set of job aids and the experimental plans for evaluating their effectiveness.

Task 6. Test job aids. —The purpose of this effort is to test the effectiveness of the prototype job aids. If they are acceptable, then they will be produced during Task 7 in the desired quantities.

The approach to testing the job aids will be dictated by the experimental design delivered from Task 5.

Task 6 personnel will probably be able to use the mission simulators and other training equipment and facilities produced by G-13 for carrying out research.

The research will have to be preceded by selection and acquisition of experimental subjects. The subjects will also have to be trained to use the job aids so that they may be tested in a simulated operational environment. After experimentation has proven the effectiveness of the job aids, activity G-13 should be provided with updated data on requirements for training personnel in the use of the aids.

Task 7. Produce job aids.—This is the final task in the series. The output of this task is a set of job aids in sufficient quantity for the life of the operational system plus a data package. The data package would be distributed to activity G-18 and G-20. One copy of all job aids would be useful in G-13. At least one copy will be needed in H-10.

The data package portion of the output, as described earlier, would be in two parts:

1. Data which state that when the job aids are used in the operational situation, man's performance will yield the required output.

2. Information which proves that the job-aid set for the remote and local segment does not exceed the dollar, weight, power, and volume budget restrictions.

Even after job aids are produced, completing activity G-15, they will have to be altered because of subsequent test results. The results are almost sure to show that some changes in the job aids are necessary.

XIV. DEVELOPMENT AND FABRICATION OF TRAINING MATERIALS, A TRAINING PROGRAM, INSTRUCTOR SELECTION AND TRAINING MATERIALS, AND THE TRAINING PLANT

Activity Group Requirements and General Considerations

Training is one of the three principal methods by which job performance capability of crew members is obtained. The other two methods are selection for job performance capability and job-aiding of job performance. Typically, the burden falls upon training to provide for all of the performance capabilities that the other two methods do not or cannot provide for. In this chapter, we consider the activities which develop the set of materials necessary to carry out a training program. Generally, activities in this group are focused upon providing:

1. Training materials, including training devices and printed materials.

2. A training program which outlines the sequence of events by which training will be accomplished and which provides tests that may be used to evaluate progress through the training program.

3. Materials for training instructors and instruments for selecting them.

4. A training plant.

In short, what must be provided includes everything necessary for the conduct of a training program except:

1. Job aids;
2. Selected candidates for training;
3. Selected and trained instructors.

Taken together, all of the outputs of the activities in this group must enable the training program to be carried out within the dollar resources and time allocated to it in the overall design of the development cycle. The true test of the training materials takes place in the training program; quality is determined when the graduate trainees are evaluated in terms of their job performance capabilities. The activities which provide the materials for the training program exercise such control over that program that any failure of graduate trainees will most often be traceable to poor implementation of the activities described in this chapter.

Relation of Activity Group to Development Cycle Model

Preparation of a training capability is represented by one activity in each branch of the development cycle model. One activity provides for the development of a capability for training personnel for the remote segment (G-10), and one provides for the local segment (G-13). The following discussion will treat the local segment, activity G-13; in general, the observations apply to G-10 for the remote segment.

As in the case of the majority of activities in Phases II and III, activity G-13 has an important antecedent in activity D-7. It is in activity D-7 that there must be a preview of the training materials and training problems engendered by decisions made there. While no firm decisions with respect to training materials are made in D-7, data which describe how training might be carried out are generated and become basic data which must be considered when carrying out G-13. In Functions E and F, all of the activities which generate requirements for human performance in the system must also look ahead to the training materials and training problems that are "bought" along with the performance allocations. As the total complement of tasks to be assigned to each crew member is filled up, there must be more and more detailed anticipatory consideration of the manner in which training will be carried out, and of the training materials that will be required. By the beginning of Function G, a fair amount of such data will have been generated. These data will be employed as a basis for decisions in activity G-6, which prepares the requirement statement for activity G-13. It is in G-6 that firm allocations of performance are made to each crew member, and it is in this activity that decisions are made with respect to which performances will be obtained by training, which by selection, and which by job-aiding.

G-13 responds to the requirement statement of G-6; its output is integrated with other interim and final personnel products in activity G-18, which is, like G-6, a crew package activity. Any adjustment which might be required in the training materials, the training programs, the instructor selection training materials, or the training plant should be accomplished within Function G, for the training materials are needed to carry out training in Function H. A final adjustment in the training materials and the training program may be required subsequent to the selection of candidates for training in activity H-6. Adjustment would be necessary to compensate for differences between the actual capability of selected trainees and the hoped for capabilities.

Resources Needed

The variety of personnel skills, of equipment, and of data resources required to carry out this activity is greater than for any other. In part, this is so because this is a "fabrication" activity in that it produces "hard" end products. The end products are, however, interim end products, none of which appear as components of the delivered operational system.

Five categories of development may be conveniently identified within this activity. They are:

1. Training program development;
2. Training equipment and materials development;
3. Training evaluation technique development;
4. Instructor capability development;
5. Support and facilities development.

The following personnel capabilities are needed for the development of the training program:

1. The capability to use task analysis and sequencing data to specify task training procedures;
2. The capability to use task performance data to specify the ancillary knowledge which must be presented;
3. The capability to develop procedures for presenting ancillary knowledge;
4. The capability to use operational performance to synthesize tasks into simulator training procedures;
5. The capability to develop training materials requirements;
6. The capability to decide as to the appropriate use and form of training materials to achieve specific training goals;
7. The capability to integrate the above into a training program which specifies curricula and course content for both instruction periods and laboratory exercises.

The development of the training equipment requires the capabilities to:

1. Analyze operator performance characteristics;
2. Develop specifications for training equipment for task and simulation training;
3. Develop specifications for support equipment to support the training equipment;
4. Develop test and checkout procedures for both training and support equipment;
5. Procure training and support equipment;

6. Analyze operational environment effects on performance;

7. Analyze the operational input;

8. Develop specifications for the input stimuli for both task and simulation training;

9. Develop methods for generation of the input stimuli;

10. Develop specifications for devices to generate the input stimuli;

11. Procure stimulus input devices.

The development of training evaluation techniques requires the capabilities to:

1. Determine data analysis requirements to compare performance requirements and performance measures;

2. Determine data analysis output required;

3. Select or prepare data analysis and comparison procedures;

4. Specify data input format required by analysis procedures;

5. Arrange for equipment to perform analysis;

6. Specify personnel requirements.

The development of an instructor capability requires the capabilities to:

1. Identify instructor training tasks;
2. Produce instructor selection instruments;
3. Identify ancillary knowledge which the instructor needs to know;
4. Produce training materials;
5. Select candidate instructors;
6. Produce a training program;
7. Train the instructors.

The development of support and facilities requires the capabilities to:

1. Specify training and support equipment maintenance procedures;
2. Specify maintenance equipment;
3. Specify maintenance personnel requirements;
4. Analyze instructor requirements for the training program, trainee volume, and use of facilities;
5. Estimate magnitude and type of support services required;
6. Specify administrative support personnel requirements;
7. Analyze facilities use, equipment requirements and characteristics;
8. Estimate facilities requirements;
9. Design facilities;
10. Prepare construction drawings for facilities;
11. Analyze training requirements, procedures and methods;
12. Design a test of the adequacy of the training capability;
13. Prepare procedures and materials for implementation of the test.

For training program development, one prime requisite will be a good library of training procedures. In addition, the use of experimental fabrication tools and personnel may be required if there is a strong need to test new training techniques. Training equipment development may sometimes be a little development cycle in its own right. If training equipment includes some advanced simulator hardware, for example, then the needed equipment might include everything from a good library to a complete hardware fabrication facility.

Fabrication of All Training Materials and Accessories Necessary for Training Crew Members
Activity G-10 (Remote)

This activity is concerned with preparing for the training of crew members for the remote segment. Its output includes: (1) fabricated training materials including training equipment, printed materials, audiovisual materials, and so forth; (2) a documented training program which completely prescribes the activities by which training is to be carried out and which includes the testing materials to be employed in the course of training; (3) materials to enable the selection and training of instructors; and (4) a selected (or fabricated) training plant.

The input to this activity derives from G-5, a technical management activity. The input will identify the job performance to be promoted by training, and the crew members responsible for each identified element of performance. It will also identify the basic capabilities to be obtained by means of selection, and the job performances that will be supported by means of job aids. It will call for the development of all the materials necessary to carry out training for the remote crew, and it will identify the numbers of personnel to be trained.

Activity G-13 (Local)

This activity is preparatory to the training of the crew members for the local segment. Its output must include all of the materials necessary for carrying out the training program except selected candidates and job aids. The categories of outputs required are the same as for activity G-10. The input is similar to the input to G-10. It derives from G-6, a crew package technical management activity.

Discussion

This section describes a typical procedure for preparing a training capability. There are 28 constituent activities involved in the method presented here.

Figure 16 shows the relationships among the activities that may be required to fabricate a training capability. The activities depicted in Figure 16 may be divided into five familiar categories:

1. Training program development;
2. Equipment development;
3. Development of techniques for training evaluation;
4. Instructor capability development;
5. Support and facilities development.

We will discuss the categories in sequence, identifying the activities which belong to each category.

I. Development of Techniques for Training Evaluation

There are two major subactivities in this development activity:

1. Develop requirements for data processing (G-13.14);
2. Specify processing equipment, procedures and personnel (G-13.15).

1. Development of requirements for data processing (G-13.14). — The purpose of this activity is to determine the computations which will be required to assess the completion of a particular phase of training, or of the training program. The procedures for the use of performance data to determine when a trainee may move on to the next phase of the training program, or when he has completed the training program, are determined in this activity.

The requirements for this activity are to provide a specification for data-processing equipment needs, personnel needs, and procedural needs. These are stated in terms of required computational needs. This statement of computational needs is used in activity G-13.15 to select data-processing procedures, equipment, and personnel.

The initiating input is from G-6; i.e., the specification of the complete training package requirements. Included in this package of requirements one

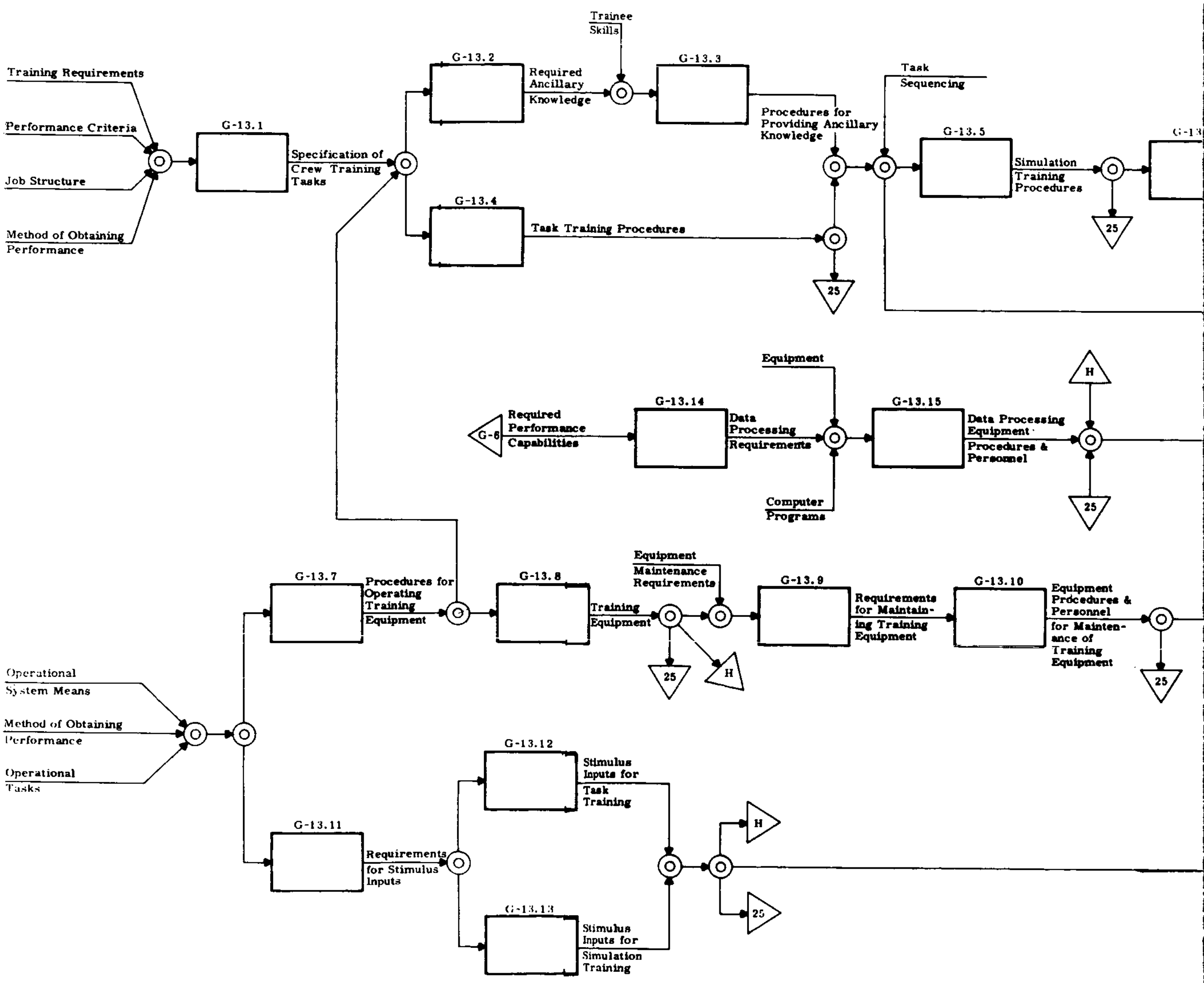


Figure 16. Function flow diag
of a training capab

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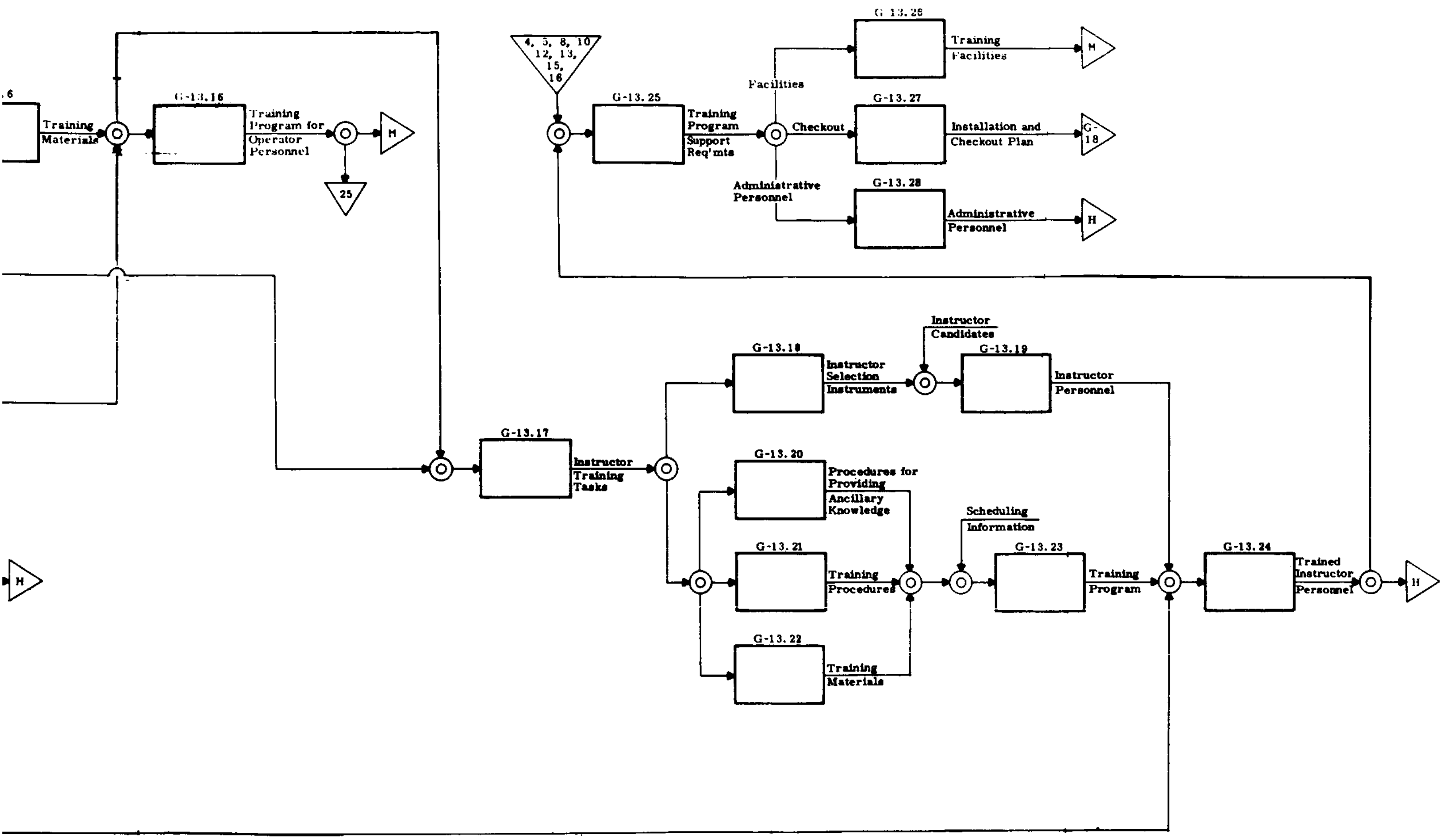

ram of the activities included in the fabrication
ility for training operational personnel.

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would find a statement of the acts of measure which are to be used to assess each element of training. These data initiate the development of requirements for data processing.

The sort of computations which may be required here are ordinarily statistical ones. There are three types of statistical techniques which might be employed. One of these is analysis of differences where the difference to be assessed is the deviation of performance from the established standard. A second is trend analysis where the trend is established by a running average approximating the standard as an asymptote. This choice would have to be accompanied by an assessment of the fiducial limits for each of the averages computed to determine when the standard was within the expected range of the average value. The third possibility would be a correlation technique based on successive blocks of performance trials. Evaluation of this technique would require the determination of the range of correlation values for the size of the block of trials selected.

2. Specify processing procedures, equipment and personnel (G-13.15). — This activity is intended to determine the computer programs, the computers, and the personnel types who use programs and computers to turn out the required analyses. These entities generate the analyses which will be used to evaluate the performance of the trainees and to help determine when training is completed. These are the means which will generate the data for the determination that the performance criteria are (or are not) met. The output of this activity is used in activity G-13.16, Develop training program for operational personnel.

The initiating input to this activity is from the previous activity; i.e., the decision as to data-processing requirements. In addition to these initiating inputs, data are required on the availability of computing equipment and statistical programs for these items of equipment which could handle the volume of data which would be generated.

II. Training Program Development

Training program development consists of seven activities:

1. Specification of operator training tasks (G-13.1);
2. Specification of ancillary knowledge requirements (G-13.2);
3. Specification of procedures for imparting ancillary knowledge (G-13.3);
4. Specification of task training procedures (G-13.4);
5. Specification of simulation training procedures (G-13.5);
6. Development of training materials for task and simulation training (G-13.6);
7. Development of a training program for operational personnel (G-13.16).

1. Specification of crew training tasks (G-13.1). — The specification of crew training tasks is only indirectly related to the operational system. However, its importance lies in its output to subsequent activities in the development of the crew training program. It is here that it is determined what training tasks will be used to develop the operational performance capability. The operational performance is analyzed to determine the training tasks to be presented to the trainees.

The output of this activity is used in the specification of ancillary knowledge requirements, activity 2, and in the specification of task training procedures, activity 4. The output which is used in these two activities is a detailed statement of all of the tasks which the trainees will experience in the training program. This description would include the following:

1. Crew tasks component in the operational performance, e.g., calibration of equipment, search, detect, and lock-on and track;

2. Task sequencing, as in the above example;

3. Accuracy of task performance, as required, e.g., calibration and tracking would have accuracy requirements in the above example;

4. Time constraints on performance, as required, e.g., search and detect and lock-on may well have time constraints as in the above example.

The initiating input for this activity (from G-6) is the specification of the job structure and the fact that the indicated performance would be achieved through training. In addition to this initiating input, the completion of the task analysis would also require the specification of performance criteria and of the method which would be used in the operational system to achieve the indicated operational performance. The performance criteria provide an indication of when the operational performance has in fact been achieved. The means to be used in the operational situation indicate the sequencing of task elements.

2. Specification of ancillary knowledge requirements (G-13.2). — Almost all operational performance involves cognitive as well as perceptual and motor aspects. It is the purpose of this activity to isolate the cognitive, or subject matter skills, required to perform the indicated sequence of tasks. If the operational performance under consideration is the making of navigational readings, the crewman must know the location of the stars he wishes to sight upon as a function of the position of the spacecraft and the time of the year. Depending upon the method of navigation to be employed, he may have to be able to use special tables or may have to make certain computations. In the case of spacecraft maneuvers, computation made by the crew members can be important.

The output requirement for this activity is the specification of the ancillary knowledge, and the amount of detail for such knowledge for each of the several operational performance capabilities. This output is used in activity 3 to specify the procedures which will be used to provide the trainee with the required information, if he does not already possess such.

The initiating input for this activity is the output of activity 1, the specification of all of the tasks which the trainee will experience in the training program.

3. Specification of the procedures for imparting ancillary knowledge (G-13.3). — Each of the subject matter requirements isolated in activity 2 must be taught to the trainees. It is the purpose of this activity to provide the procedures whereby this may be accomplished. There are a variety of procedures which present themselves for this purpose. Among these are the traditional lecture, assigned readings, teaching machines, films and television. In the accomplishment of this activity, each knowledge area might be outlined in the necessary detail and the most appropriate method of conveying the information would be chosen. It is desirable that the method chosen be capable of capitalizing on that knowledge which the trainees bring with them.

The output of this activity — the procedures to be used to impart the ancillary knowledge — is used in activity 5, specification of simulation training procedures, and in activity 16, development of a training program for operational personnel.

The initiating input for this activity is the output of activity 2, the ancillary knowledge requirements. For the completion of the activity, however, further inputs are required. These are knowledge of appropriate training procedures and the conditions which dictate their use, as well as some indication of the kinds and amount of knowledge which the trainees may be expected to bring to the training program.

4. Specification of task training procedures (G-13.4). — This is a parallel activity to activity 3. The purpose here is to determine the series of training steps which will be utilized to provide the trainees with the requisite perceptual motor behaviors which will be required for performance in the operational situation. These procedures will, of necessity, be built around the requirements for operation which are dictated by the means designated for the operational system.

The output of this activity, the procedures for training tasks, will be used in activity 5 to provide an input to the development of procedures for simulation training. These will be used in activity 6 to provide an input to the development of training materials. They will also be used in activity 16, the development of a training program for operational personnel, and in activity 25 to develop training program support requirements.

The initiating input for this activity is the output of activity 1, the training tasks which must be presented to the trainees. However, two other inputs are required, both of which come from activity G-6. These are the job structure and the method to be used to obtain performance in the operational situation. These inputs are required because the behaviors which the trainees require must be those which are needed in the operational situation. Therefore, the given procedures must point the acquisition of behavior toward the specified job structure and must also prepare the trainee to work with a particular means in the operational situation.

5. Specification of simulation training procedures (G-13.5). — Assuming that the trainees acquire the necessary task performance capability, this capability must be integrated into efficient operator performance. This further refinement of skills is achieved through the medium of simulation training. It is this performance, developed in the simulator, which is called out in the design phase of the development cycle. It is this performance to which the performance criteria properly apply. It is this performance capability which the crew members will take to the operational setting. The output of this activity is the procedures which will be used in simulator training to provide the operational performance capability.

The output of this activity — the procedures for simulation training — is used in activities 6, 16, and 25. Activity 6 provides training materials for both task and simulation training. Activity 16 is where the training program for operational personnel is developed. Finally, the output of this activity is used in activity 25 to develop training program support requirements.

The initiating input for this activity is the description of the task training procedures which is the output of activity 4. Additional inputs, shown in Figure 16 as coming by way of activities 1 and 4, are the structure of the operational job and the means to be used in the operational system. A final input is information concerning the possibilities for task sequencing in the operational system. Given these inputs and data on the ancillary information requirements and means for providing this information, the procedures for simulation training may be constructed. It is useful to identify three aspects of simulation training. First, is the normal, or expected, mode of operation. Second, is a contingency mode of operation which may arise because of the exigencies in the usual operational environment of the aerospace system. The third is a contingency mode of operation which may arise as a consequence of failure in some part of the spacecraft itself. This latter is the sort of thing which is usually thought of as an emergency. The simulation training program must be capable of considering all three of these modes of operation.

6. Development of training materials for task and simulation training (G-13.6). — In this context, training materials may be thought of as any aid to the achievement of performance. This includes special training aids, which will be used in the training situations, and then only so long as they are necessary to support and sustain performance.

The requirement for the output of this activity is in activity 16, which is responsible for the development of the training program, and in activity 17, which is responsible for the development of tasks for training instructor personnel.

The initiating input for this activity are the task training procedures developed in G-13.4. However, completion of the activity requires the input from G-13.3, the procedures for imparting ancillary knowledge, and from G-13.5, the procedures for simulation training.

7. Development of a training program for operational personnel (G-13.16). — The outputs of the previous six activities are brought together in this activity

to organize them into an integrated training program to prepare crew members to perform the required operational and maintenance tasks. The curriculum of this training program consists of courses composed of related operational performance. Each course would require the assimilation of subject matter knowledge and a portion of it would be devoted to the practice of associated perceptual motor behavior.

The output of this training program development activity goes to G-16 for the synthesis of the several methods of obtaining operational performance, and also to H-10, where the actual training of the operational personnel occurs. Finally, the output goes also to activity 25 to contribute to the specification of support requirements for the training program.

The initiating input to this activity is the specification of the task training procedures, but only because these are likely to be available first. To complete the training program development, the outputs of all of activities 1 through 6 must be available. In addition, an input from activity 15, the specification of the procedures for evaluation of training performance, is required. This latter is necessary so that data may be provided for processing to meet the demands for analyses. Finally, for the completion of the training program development, it would be desirable to know something about the expected scheduling of personnel through the program. Given the scheduling data one could anticipate the through-put requirements, hence the number of replications of courses and the requirements for instructor personnel and expendable materials.

III. Equipment and Stimulus Input Development

This function consists of seven (7) activities:

1. Determine mode of operation of training equipment (G-13.7);

2. Obtain training equipment (G-13.8);

3. Determine requirements for maintaining training equipment (G-13.9);

4. Obtain equipment, procedures and personnel to maintain training equipment (G-13.10);

5. Determine requirements for stimulus inputs for training (G-13.11);

6. Obtain stimulus inputs for task training (G-13.12);

7. Obtain stimulus inputs for simulation training (G-13.13).

1. Determine mode of operation of training equipment (G-13.7). — The purpose of this activity is to specify the manner in which the training equipment is used by the trainee to perform the specified training tasks. The output of this activity is, for all practical purposes, a procedures manual which may be used by the trainee to learn to operate the training equipment. Each of the items of training equipment must have such a procedures description. This description must include all of the instructions for the use of the given equipment to perform the tasks to be learned by the trainee. This set of instructions will differ from procedures manuals per se in that it may not include the use of job aids.

The requirements for this activity come from activity 4, the development of procedures for task training. The equipment operating procedures are used in conjunction with training tasks from activity 1 to specify the task training procedures for the training program.

The initiating input for this activity is the method of obtaining performance which was specified in G-6. In addition, it is necessary to have information about the means to be used in the operational system and the tasks to be performed in the operational system. These latter items of information are required to ensure that what the trainees learn to do will be consonant with what they will be required to do in the operational situation.

2. Obtain training equipment (G-13.8). — This activity is concerned with the procurement of the training equipment. Generally, two avenues for obtaining training equipment are open. The first is to adapt items of operational equipment to accept a synthetic input and thus metamorphize into training

equipment. The second is to develop and procure separate and distinct items of equipment for training. If the former method is chosen in a given instance, then activity G-13.8 is a procurement activity. If the latter method is chosen, then G-13.8 would have to be expanded to include design, specification, breadboard, production, test, etc. activities.

The output of this activity is hardware, i.e., training equipment. This output, or its consequences, is required in activities G-13.9, G-13.25, and in activity H-10. In G-13.9, the consequences of the output are analyzed to determine equipment maintenance requirements. In activity G-13.25, this output enters into the determination of the requirements for support for the training capability. The output is used in H-10 for the actual training of the operational personnel.

The initiating input for G-13.8 is the specification of the method for obtaining performance capability which is the output of activity G-6. In addition, information about operational system means and operational tasks is required so that the training equipment will call out the same kinds of behaviors as the operational equipment.

3. Determine requirements for maintaining training equipment (G-13.9). — The maintenance of the training equipment is in fact a support activity. However, it is necessary to determine how this support activity will be conducted, as well as the people, equipment, and spares necessary to conduct the maintenance activity. G-13.9 is intended to provide this information. There are two classes of training equipment. One is that equipment which is used by the trainees to acquire operational performance capability. This is what is usually thought of as training equipment. The second includes all of the other items of equipment required to support the training program, including the support of the equipment items in class one. Activity G-13.9 applies to all of the items in both classes.

The requirement for this output is in activity G-13.10, where the requirements are translated into actual entities. The requirements are translated into people with skills, into maintenance procedures and equipment, and into spares for use in maintenance tasks.

The initiating input for G-13.9 is the output of G-13.8 which is the training equipment. In addition, it will be required to know something about the preferred modes of maintaining each of the items of equipment. For off-the-shelf items, the manufacturer may recommend a maintenance regimen. If such cannot be obtained, then a regimen may be developed from knowledge of the types of equipment and the state of the art as regards maintenance.

4. Obtain equipment, procedures, and personnel to maintain training equipment (G-13.10). — The purpose of this activity is to provide the necessary capability to maintain the training equipment. Maintenance personnel, as well as procedures and equipment for these personnel to use, is obtained in G-13.10. The reader should understand the term equipment to mean tools, in the broad sense, and also spares.

There are two requirements for the output of G-13.10. The first of these, in the sense of most immediately, is in G-13.25 to contribute to the determination of the requirements for support of the training capability. The second of these is in activity H-10 where operational training is conducted.

The initiating input for G-13.10 is the output of G-13.9, the specification of the requirements for maintaining the training equipment.

5. Determine requirements for stimulus inputs for training (G-13.11). — This activity is responsible for generating the requirements for the inputs for all of the training activities. These inputs are used by the training facilities to present information to the trainees which stimulates them to respond in the manner dictated by the operational procedures. As examples of stimulus inputs consider:

1. A star field for practices of navigational sightings;

2. Vehicle motion to stimulate kinesthetic and vestibular cues;

3. Roll, pitch or yaw data presented on an 8-ball type display;

4. Ground targets for practicing detection and tracking activities;

5. Characteristics of the surface of a planet to be used to select landing sites.

The output of this activity is a precise statement of the input stimuli required.

This output is used in G-13.12 and G-13.13 to provide the required stimulus inputs for task and simulation training, respectively.

The initiating input for activity G-13.11 are data on operating tasks and the means for achieving operational performance, both of which come from activity G-6. The information on the operational performance provides data concerning the type of stimulus input. The operational system means provide data on the characteristics which the operational input will possess.

6. and 7. Obtain stimulus inputs for task (simulation) training (G-13.12) (G-13.13). — These two activities will be discussed together although they are presented separately in Figure 16. While the kinds of things to be done are the same, the output of G-13.13 may be much more extensive as regards quantity, relatedness between elements of the input, and fidelity to the operational input. It is the responsibility of these activities to take the requirements for input materials as developed in G-13.11 and to combine these requirements with a method of input production to obtain the necessary input materials.

The output of G-13.12 and G-13.13 is used in activities G-13.24, G-13.25, and H-10. In G-13.24, these materials will be used in the training of instructor personnel. In G-13.25, they will contribute to the specification of requirements for support of the training capability. In H-10, they will be used to train operations personnel.

For both G-13.12 and G-13.13, the initiating input are the requirements for the stimulus inputs which are the output of G-13.11. Given these requirements and information on methods for producing the input materials, the activities may be accomplished.

IV. Instruction Capability Development

Many of the activities to be described here are analogous to those described above (Training Program Development). Where this is the case, the reader will be referred to the previous activity. The discussion will consider only the requirements and the initiating input. The development of support facilities for the training capability consists of 8 activities:

1. Develop training tasks for instructor personnel (G-13.17);

2. Develop instruments to select instructor personnel (G-13.18);

3. Select instructor personnel (G-13.19);

4. Develop procedures for providing ancillary knowledge to instructor personnel (G-13.20);

5. Develop procedures for training instructor personnel (G-13.21);

6. Develop materials for training instructor personnel (G-13.22);

7. Develop a training program for instructor personnel (G-13.23);

8. Train instructor personnel (G-13.24).

1. Develop training tasks for instructor personnel (G-13.17). — This activity is analogous to G-13.1. Indeed, if the output of G-13.17 did not depend on that of G-13.1, the two could be accomplished in concert. The requirement for the output of G-13.17 is in G-13.18, G-13.20, G-13.21, and G-13.22. G-13.17 uses the output to develop instruments for the selection of candidates to be instructor personnel. The other three activities use the output to help develop procedures for imparting ancillary knowledge, procedures for training candidate instructor personnel, and for preparing training materials for training instructor personnel, respectively.

The initiating input for activity G-13.17 are the task training procedures from G-13.4 and the procedures for imparting ancillary knowledge to operations personnel from G-13.3.

2. Develop instruments to select instructor personnel (G-13.18). — The purpose of this activity is to develop a set of procedures whereby candidate instructors may be screened and suitable candidate instructors may be selected. The problem is to first list the properties which an individual should possess to be an instructor. Second, one constructs a method of testing to determine whether the candidate possesses the property in question. When each of the properties has been matched up with a procedure which tests for the existence of the property, these procedures are combined into a test set for selecting instructor personnel. This test set is called an instrument for selecting instructor personnel.

The requirement of this instrument is in activity G-13.19, the immediate follow-on activity to G-13.18. Here the instrument is used to select personnel who will serve as instructors in the training program.

The initiating input to activity G-13.18 is the statement of training tasks for instructor personnel which comes from G-13.17. It is also necessary to have available information on the trainee tasks and ancillary information requirements. From these three inputs it may be determined what knowledge and skills the candidate instructors must bring with them.

3. Select instructor personnel (G-13.19). — The purpose of this activity is to administer the selection instrument developed in G-13.18 to select candidates for instructors in the training program which is under development. For the details of this activity, the reader is referred to activity H-6 of the fabrication phase of the development cycle (Chapter XI). Activity H-6 is concerned, in part, with the selection of personnel for the operational training program. The procedures, if not the content of the selection instruments, would be the same for G-13.19. The output of this activity are the personnel who are selected as instructors in the training program.

The requirement for this activity is in G-13.24, the activity which is responsible for training the instructor personnel to provide them with the specific skills which they require to function in activity H-10, training of operational personnel.

The initiating input for G-13.19 are the selection instruments developed in G-13.18. In addition to this input, it is necessary that candidate instructor personnel be provided.

4. Develop procedures for providing ancillary knowledge to instructor personnel (G-13.20). — The purpose of this activity is directly analogous to that of G-13.3.

The requirement for the output of G-13.20 is in G-13.23, the development of the training program for instructor personnel.

The initiating input to G-13.20 are the instructor training tasks provided by activity G-13.17.

5. Develop procedures for training instructor personnel (G-13.21). — This activity is directly analogous to G-13.4.

The requirement for the output of this activity is in G-13.23, the development of a training program for instructor personnel.

The initiating input to G-13.21 is in G-13.17, the instructor training tasks.

6. Develop materials for training instructor personnel (G-13.22). — The purpose of this activity is directly analogous to that of activity G-13.6.

The requirement for the output of G-13.22 is in G-13.23, the development of the training program for instructor personnel.

The initiating input to G-13.22 is in G-13.17, the instructor training tasks.

7. Develop a training program for instructor personnel (G-13.23). — This activity is directly analogous to activity G-13.16.

The requirement for the output of this activity is in G-13.24, which is devoted to the training of instructor personnel.

The initiating input to this activity is from activities G-13.20, the procedures for imparting ancillary knowledge, G-13.21, instructor training procedures, and from G-13.22, instructor training materials. In addition, it would be desirable to have some scheduling information concerning the rotation of instructor personnel for the different types of courses through the training program. Such information would facilitate the arrangements for training facilities and for expendable resources.

8. Train instructor personnel (G-13.24). — The purpose of this activity is to train selected personnel to perform as instructors in the operational training program.

The requirement for the output of this activity is in G-13.25 and in H-10. In G-13.25 the output contributes to the specification of support requirements for the training capability. In H-10, the output provides instructors to work in the training program. The activity is carried out in H-6 (see Chapter XI).

The initiating input to this activity are instructor trainees who come from activity G-13.19, the selection of instructor trainees. In addition to this input, the activity requires the outputs of activity G-13.20, which provides procedures for imparting ancillary knowledge, activity G-13.21, which provides training procedures, and activity G-13.22, which provides training materials.

V. Support and Facility Development

There are four major subactivities in this development activity:

1. Develop support requirements for the training program (G-13.25);

2. Develop training facilities (G-13.26);

3. Develop an installation and checkout plan (G-13.27);

4. Provide administrative personnel (G-13.28).

1. Develop support requirements for the training program (G-13.25). — Any training program requires support for it to be a success. In the present context, we conceive of trainees, training personnel, maintenance personnel and equipment, training evaluation personnel and equipment, and the training equipment as the major capability in the training program. We tend to view the facility personnel and the administrative personnel as the support capability.

The requirement for the output of this activity is in the three following activities. The first is G-13.26 which develops the training facility. The second is G-13.27 which develops the installation and checkout plan. The last is G-13.28 which is responsible for providing the administrative personnel.

The input to this activity is from G-13.4, G-13.5, G-13.8, G-13.10, G-13.12, G-13.13, G-13.15, G-13.16, and G-13.24. Each of these activities provides information for the elaboration of support requirements.

2. Develop training facilities (G-13.26). — It is the responsibility of this activity to provide adequate space and appropriate environmental control to enable the training program to operate effectively.

The initiating input for this activity is the output of activity G-13.25, especially as regards the requirements for facilities for the training capability.

3. Develop an installation and checkout plan (G-13.27). — The purpose of this activity is to provide an organized plan for installing the means which provide the training capability in the facility which will house them during the period for which they will be used to train operational personnel. In

addition to the installation of equipment, personnel, and all of the accoutrements of training, the plan shall provide for the checkout of each of these items. It is at this checkout that the initial test of the adequacy of the training program can be made. Trained personnel, in the form of instructors, will be available to serve as subjects. The test should concern itself with the capability of the training program to provide the performance capability required by the designers of the aerospace system. This is one of the earliest points at which the adequacy of the training program may be tested. If it has weaknesses, this would be the most propitious time to reveal them.

The requirement for this activity's output is in activity G-18 where all of the capability for the development of operational performance is integrated for the first time.

The initiating input for this activity is the output of activity G-13.25, the specification of the requirements for training program supports.

4. <u>Provide administrative personnel (G-13.28)</u>. — It is the responsibility of this activity to specify the various administrative skills and capabilities required to support the training program.

The requirement for the output of this activity will be in H-10, where the training of operational personnel is conducted.

The input to this activity will be the output of activity G-13.25, the requirements for support personnel for the training program.

XV. THE TRAINING OF SELECTED CREW MEMBERS

Activity Group Requirements and General Considerations

Men are employed in aerospace systems as means for implementing system functions. They are so used when they can be justified in terms of system cost and quality as the preferred method of implementation. As a system means delivered by a development cycle, man must have the capability to perform in the operational system; that is, the performance that will be needed in system operation must be latent and ready for use. There is, therefore, a need to "fabricate" or train men to provide for the needed capabilities.

As in the case of hardware we may buy or select personnel performance capabilities in the market place rather than fabricate to obtain them. Seldom, however, in the case of a complex aerospace system, can we select men who already have all of the capabilities necessary to perform system functions with the required reliability. When selected men have only some (or none) of the job-performance capabilities needed, there are two ways to "fabricate" them. One is by providing the selected men with job aids to augment their inherent capabilities. The other way is by training them so that new performance capabilities are added to their repertoires. A combination of both is usually needed. Thus, trained performance is required, in most cases, to supplement performance capabilities gained by selection and by job-aiding, such that each man to be used in the operational situation will work as needed to ensure that the operational system performs with the required reliability.

Man is only available as a prepackaged means; we must therefore work with whole men—in selection, job-aiding, and training. These three ways of obtaining needed performance capabilities interact within each man. Therefore, we must express the "fabrication" output which is required to satisfy the need for man performance capability as a set of selected, job-aided, and trained men each capable of carrying out his assigned functions.

The activity group with which we are concerned in this section is the one (as shown in the model) which follows personnel selection and the preparation of job aids. It follows job-aid fabrication because personnel must be trained in the use of job aids as well as to perform some system functions without job aids. In fact, training always follows selection, but it may in practice overlap in parallel with the preparation of job aids. Although the output of training includes reference to selection and job-aiding, it must be quite clear that no implication exists that training <u>includes</u> selection and job-aiding.

What happens if men are selected and provided with job aids, but are delivered without training? If the performances earmarked for training are operator performances either in the remote or local segment, and if nothing is done subsequently to correct for the lack of training, the outcome would certainly be an installed operational system whose probability of success would be zero. In complex systems such as aerospace systems, it is very unlikely that a selected and job-aided crew member will be able to use his "native intelligence" to perform his assigned operator functions correctly the first time through <u>without</u> training. If the untrained performance were maintenance technician performance (or support system performance), the effect would be to degrade overall system reliability. In such cases, of course, the extent of degradation would depend upon the accumulative impact of the untrained performances upon overall system reliability. In short, not to train for assigned operator performances is analogous to a failure to fabricate and install hardware which implements prime functions. In terms of overall system quality, the effect is exactly the same in both cases. Not to train for maintenance technician performance has the same effect as failure to fabricate and deliver maintenance equipment. If the effects of failures to train are to be corrected by retrofit actions, system costs will almost certainly exceed expectations. If correction is not made, the impact is solely upon quality.

In designing a system, training may be used whenever there is a cost or quality advantage to do so as compared to job-aiding or selection. Of the three methods, training (as used) tends to be the most expensive way to promote performances. It is, on the other hand, likely to be the method which is most amenable to reaction to last minute changes in system design. While selection may in theory be employed wholly in place of training, job-aiding cannot be so employed. Whenever job aids are used to promote job performance, secondary requirements are generated to teach personnel when and how to employ the job aids.

Characteristically, weight, power and volume constraints on the local segment have effects upon training that are not seen in the remote segment. Thus, these constraints limit the number of personnel who can be employed in a local segment, and may thus require that each man be given a wide variety of performance capabilities and that there be considerable cross-training in order to provide for reliability. The effects of training are subject to extinction, and for this reason, there may be reliability degradation over time. For lengthy excursions, extinction effects must be taken into account to preclude loss of reliability in the local segment. This may be done in part in training.

Relationship of the Group to the Development Cycle Model

Since we assume that men are used in both the remote and local segments, then training requirements arise in each segment. Thus, there will be two parallel lines of development involved in preparing for the training activity, one for local segment development and one for remote segment development. During the course of training, these two parallel lines of development are likely to become highly interactive inasmuch as the remote and local crews will have to be trained to interact with each other. In the discussion which follows, we will trace only the line of development for the local segment; the line of development for the remote segment is similar.

The only training activity concerned with the local segment that is explicitly called out in the development cycle model is box H-10. This box falls within that part of the development cycle which is concerned with <u>fabrication</u> of the operational system means.

There are many activities in the model which precede activity H-10 that are concerned with laying the groundwork for implementation of training in activity H-10. In Functions D, E, and F of the system development model, there are a half dozen activities that are concerned with identifying the functions that man will implement in the operational system. Activity D-7 yields an identification of all operator functions. Activities E-9 and E-10 are concerned with identifying maintenance functions; the former isolates maintenance functions on prime hardware, the latter maintenance functions on operator performance. Activity E-12 will include identification of man performances in the operation of the Human Support System. In Function F, activity F-8 identifies man performances necessary for the maintenance of maintenance technician performance. Activity F-10 determines man performances for the maintenance of maintenance equipments and the maintenance of Human Support System equipments.

Taken together, all of these activities identify what man will do in the local segment, and thus specify performances which it may be necessary to obtain by means of training. In fact, within each of these listed activities there must be consideration of whether or not the recommended allocations of performances to man will create training problems which cannot be solved. Thus, part of the output of each of the activities identified above will include data to show that if man is assigned performance responsibilities as recommended, training problems will not arise that would move the system position out of the desired cost and quality neighborhood.

All the functions recommended for implementation by man must be considered in activity G-6 where final determination is made of the total job makeup for each crew member. In activity G-13, the training materials, the training program, the training facilities, and instructor selection and training materials will be prepared. As these items which are necessary for carrying out training are prepared, job aids will be fabricated in parallel in activity G-15. The design and fabrication of these job aids will create new training requirements not specifically identified in activity G-6, and will add another element to the total training burden. Between activity G-13 and activity H-6, there will be several reviews of decisions made in Function G which are relevant to training and adjustments will typically be made. The next important activity related to training is H-6, where men will be selected as candidates for the training program. The men selected for training will be joined with job aids, the training facilities, instructors, training materials and the training program as the input to activity H-10 where training will take place.

In the "GO" model, the output of activity H-10 is a complement of fully-trained crew members. In a real aerospace system development cycle, it can be expected that there will be subsequent changes and adjustments in the system, and that deficiencies in training will be detected and additional training will be required prior to final installation and demonstration of the aerospace system. Thus, detections of training inadequacies and of hardware inadequacies which will cause retrofit training may be detected in the review and integration activities (H-14, H-16, H-18, H-19, H-20), and, as the need for changes is detected, adjustment in training may be undertaken.

It can be seen that the output of activity H-10—trained personnel—is an output which is integrated through subsequent levels of system assembly to become an integral part of the installed operational system—the output of the total development cycle.

Resources Needed

From the standpoint of resource requirements, this activity group is unique among all of the activity groups discussed. It is unique simply because the resources required to carry out training are all developed within the scope of the development cycle itself; resources from outside the development cycle are not required. Thus, activities G-10 and G-13 provide all of the basic materials necessary for training, including: training equipment, text materials, exercise materials, a training program, test materials, instructor selection and instructor training materials, and a training plant. Activities G-8 and G-15 produce the job aids that must be employed in training for the purpose of familiarizing trainees with job-aid use. Activities G-11, G-12, H-5, and H-6, taken together, account for the selection of candidates for training, and activities H-5 and H-6 provide instructors. Thus, there is provision in the development cycle model for providing all the means necessary to implement training in activities H-8 and H-10. Should a specific development cycle require training means which do not fall into one of the classes of means identified in the model, it would be appropriate to modify that development cycle to provide for the unusual training means. It follows that to identify the specific material resources required to implement training, reference must be made to those activities in the development cycle which produce the materials needed.

The Training of Crew Members
Activity H-8 (Remote)

The output of this training activity is an output of the development cycle. It is trained crew members for the remote segment. The output must also include data which demonstrate that the crew members are capable of the operator and maintenance technician performances required of them and that each performance exhibits the required reliability.

The inputs to H-8 derive from several sources. The input which contains the requirement for training derives from H-5, a crew package activity. H-5 also provides selected candidates for training and trained instructors. Job aids for use in training for the purpose of familiarizing crew members with them will derive from G-8. Training materials, training programs, and training plant will derive from G-10.

Activity H-10 (Local)

The output of this activity is trained crew members for the local segment. These crew members are physical components of the delivered operational system. Activity H-10 must provide data which demonstrate that they are capable of all of the operator and maintenance technician performances required of them, and data which show that they can be expected to perform each function allocated to them with the required reliability.

As in the case of H-8, inputs derive from several sources. Requirements for training and specification of the conditions under which the output of H-10 will be evaluated derive from H-6. H-6 also provides selected candidates for training and trained instructors. Job aids are provided by G-15, so that crew members may be familiarized with them. The training materials, the training programs, and the training plant derive from G-13.

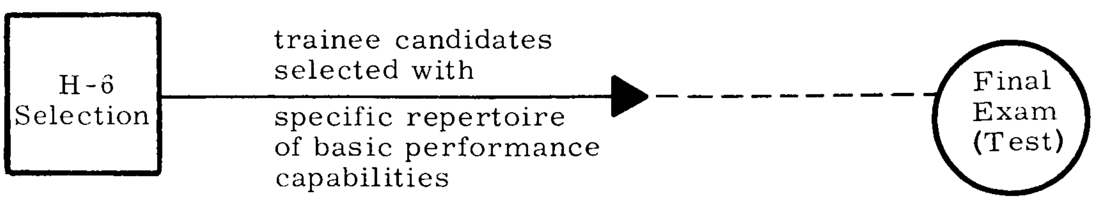
The inputs to the training activities include complete programs for carrying out crew training. Thus, it is intended that the output of Function G include a day-by-day, hour-by-hour description of how training will be carried out for each crew member. (In the discussion which follows, it will be seen that this assertion is not strictly true.) It is intended also that the output of Function G indicates what training equipment is to be employed, when it is to be employed, and how it is to be employed. Further, the output of Function G should include a comprehensive set of tests which includes all of those tests that will be employed throughout the course of training for all crew members, and a final examination for each crew member.

In the following discussion, we will attempt to describe an approach to implementation of training which not only requires that these outputs be provided by Function G, but which also makes it possible for Function G to anticipate exactly what must be employed in training and thus to produce the needed materials, tests, and programs. It will be seen that it is the main line of training that is anticipated in detail in Function G, but that there are corrective loops associated with the main line of training which cannot be anticipated in detail but which must be worked out in the course of the training activities themselves. For these corrective loops (which are really additive loops in the training program), Function G can only provide materials and guidance that are likely to be useful.

The description of the training process which follows looks at a training program from the point of view of program development. This point of view is adopted simply for expository purposes. It must be remembered that in activities H-8 and H-10 training programs will be used, not developed. If the characterization that is presented below is not a faithful representation of the way in which training is currently carried out, it nevertheless reasonably well serves our first purpose which is to provide a basis for identifying what is needed to implement the training activities.

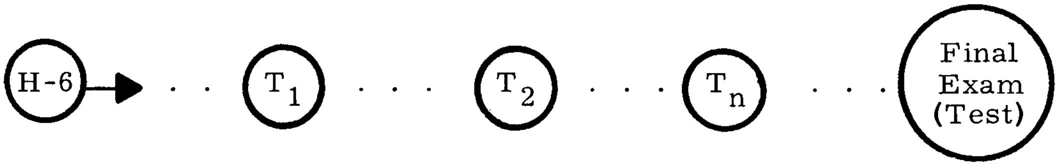
Those who must devise the training program have one all important objective toward which they must strive. That objective is to prepare a training program in such a way that the graduates of the program, when supplied with the job aids and other materials they need, will be capable of exhibiting those human performances which are needed in the operational system. Thus, their objective is to devise a program which will prepare the trainees to take a "final exam." That final exam is *defined* by the set of performance capabilities which man must supply to the operational system. Notice that we say the exam is *defined* by these performance capabilities, rather than saying that the exam *is the exhibition* of these performance capabilities. This is because we use the complete set of objectivelydefined operator and maintenance technician performances for each crew member to establish the objective of the training program; we call the description of that set a "final exam" when *all* of the performances are described in a manner that provides a basis for evaluating a graduate trainee's capability to perform as required in the operational system. In general it is not possible to employ the complete final exam as a final test—although it is necessary that the final exam be documented so that there is a specific public and "inspectable" statement of training objectives. We will call the test, which is given at the end of training, the *final test.* The results of this test must correlate with the results that would be obtained if the final exam were given so that final test results may be used to predict fitness of trainees for performance on the job.

It must be clear that the goal of training is to enable trainees to "pass" the final exam; it is not to train them to pass a specific final test.



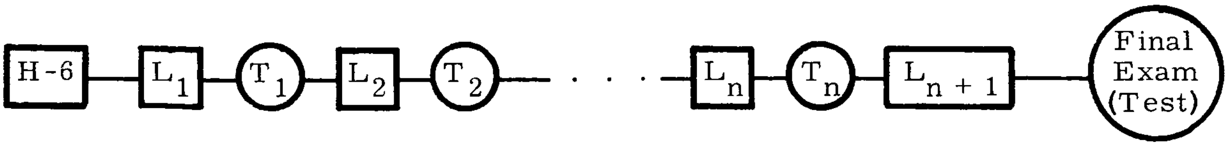
The training program designers know what they have to work with in the way of the basic performance repertoires of the prospective trainees (the output of the selection activity, H-6). They also know precisely how the trainees must be measured at the end of the training program (the final test) and what the target performance capabilities are (final exam).

The next task confronting the development of the training program is to devise a sequence of tests, $T_1, \ldots T_n$ to be inserted between H-6 and the final exam. The situation then becomes:



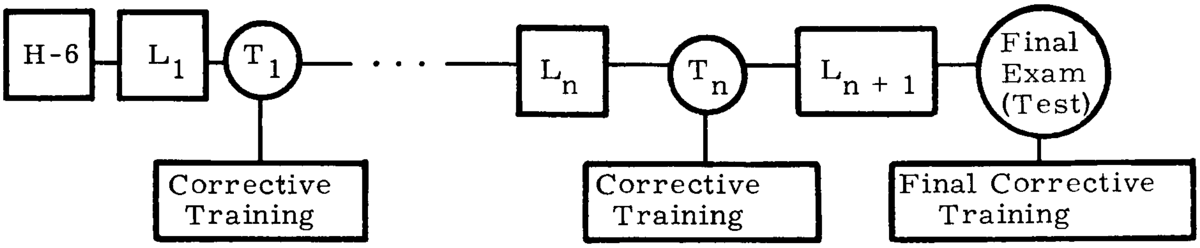
Each test represents a point where a specified set of responses is desired from the trainee. The sets of responses are sequenced so that later sets build upon earlier ones, and so that they culminate in the set of responses defined by the final exam.

In addition, for each test there must be a clearly available training package which will enable the trainee to achieve the response required by the test, provided only that he was able to respond successfully to the previous test. Thus, we are not finished laying out the sequence of responses to be tested for until we can be sure that there exists for each test point a possible training package which will enable the trainee, who has responded successfully to the previous test, to respond successfully to the following one. Let us denote the training packages which prepare the trainee for the successive tests as $L_1, L_2, \ldots L_{n+1}$ (L for lesson). Then the pictorial situation becomes:



Thus, we have a sequence of lessons which, starting from the raw trainees provided by H-6, molds their behavior characteristics until the behavior demanded by the final exam is achieved. Sometimes it turns out that each lesson adds a few new performance capabilities which are directly needed in the final exam. The above process then may be viewed as a process of attaching performance capabilities to the trainee's repertoire a few at a time, until he has all that he needs. Other times, however, not every lesson will add a performance capability which is needed directly for the final exam. Rather, a given lesson may provide the trainee with behavior characteristics which do nothing more than provide the foundations for a later lesson.

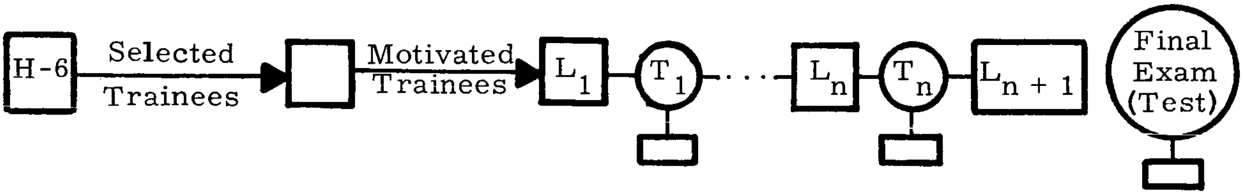
With this approach a test is never made, unless there are alternative courses of action which depend on the test results. Thus the next task which must be accomplished is that of devising corrective training procedures at each test point, in case the trainee does not fare well in testing. Corrective training procedures may be very involved and lengthy, but we shall indicate symbolically the corrective training function (no matter how complex in reality) at each test point by a single box:



Each corrective training box has a need for a training program of its own. The same techniques may be used to provide each of these little training programs as are used to provide the overall training program. Corrective training is needed in order that the overall training program may have the required probability of success.

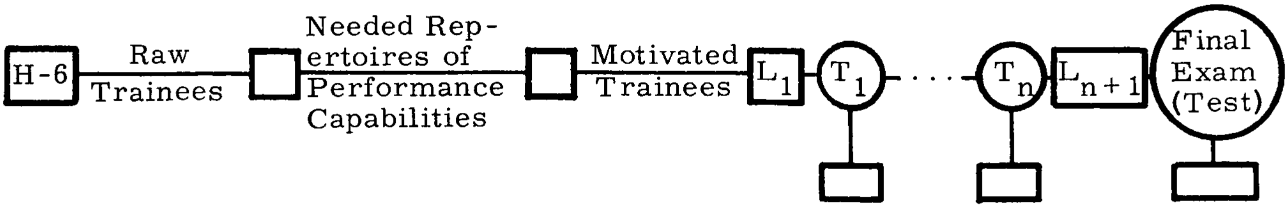
So far, in the discussion of the training program, one very important function is missing, a function to provide the trainees with an underlying goal direction, or motivation, to support them throughout training. Motivation provides an "internalized" stimulus which, when accompanied with the stimuli from the training lessons, provides the complete set of stimuli needed for learning. When the final exam is passed by the trainee, he should recognize that his goal has been achieved, and those motivating stimuli peculiar to training should be shut off. To this end, it will generally be quite useful to utilize the motivation function to provide the trainees with a good clear picture of their final exam. In addition to telling the trainee when his training motivation may be "turned off," familiarity with the final exam helps the trainee to separate those things in the training program which are particularly important and applicable to him, from those which are not.

Thus, the next task is to devise the motivation function which will provide the trainees goal direction throughout the training program. With this additional function, the picture of the training program becomes:



There is one last function which is not included in the above picture, which must be taken care of. The problem is that the prospective trainees, which the selection activity (H-6) turns out, may not in fact have the basic performance repertoire needed in the training program. Therefore, a function must be inserted just after Box H-6, whose input is the set of raw trainees selected by H-6, and whose output is the set of trainees with the required basic repertoires of performance capabilities. This function corrects any failures of activity H-6.

The next task of the training program then, is to devise a method for implementing this function. With this final function the training program becomes:



This completes the development of the training program. What is finally provided to the personnel who conduct training is an outline, like the one above, of the functions to be performed during training, with detailed instructions on how to implement each function.

Up to now, however, the picture above does not indicate the inputs that are needed from outside sources during training. From activity G-13 instructors are provided as they are needed to the various training lessons, $L_1, \ldots L_{n+1}$. In addition, G-13 provides the training materials and facilities as they are needed in the training lessons. The prototype job aids which might be required in each lesson are input from activity G-15. When there is a need for instructing the trainees in the use of the materials for maintaining human performance, these materials (or prototypes thereof) will be provided by activity H-11. (It should be observed that the training activity itself may provide an input to H-11 if new requirements for materials to maintain human performance are discovered during training.)

Serendipity Associates
Chatsworth, California, October 1966

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PART B

DEVELOPMENT OF MAN-MACHINE SYSTEMS:

Some Concepts and Guidelines

PART B

CONTENTS

Page

I. INTRODUCTION

In the world of human factors as it is applied in the design and development of aerospace systems, a jargon has evolved. In part, the terms in the jargon have been developed in universities where human factors is given formal consideration as a discipline. And, in part, these terms have come into wide usage because they have been set down in Air Force Manuals, Navy Directives, and NASA Policies. Of all the Government agencies which employ numbers of human factors personnel, the Air Force has probably contributed the greatest number of concepts and terms. Concepts and terms which are defined for use within the Air Force come to be used broadly outside of Air Force programs, simply because the human factors people who work on Air Force programs subsequently work on other non-Air Force programs and carry their terminology with them. Some of the terms which are employed by human factors and biotechnological personnel have relatively long and impressive histories and are used with essentially the same implication by all professionals. At the other end of the continuum there are words which have been introduced recently and which are used only locally, and then without consistency. We may ignore the terms at the latter end of the continuum, but the terms which are used broadly and generally with consistency are important to information commerce not only among human factors personnel, but between human factors personnel and others engaged in aerospace system development. Where such terms are "bad" they cannot be stricken from use; they must be accepted and integrated, and, in effect, "made good."

This report is the fourth part of a series. In Reports IA, IB, IIA, and III a relatively restricted and well-defined set of terms relating to human factors activities and system development is employed. In these prior reports those words in the vernacular which might give rise to confusion or ambiguity in reading and using the reports have been avoided. Although it was deemed desirable to avoid the use of such terms in the previous reports, it is certainly not desirable to avoid them altogether. What has been said in the previous report must be articulated with the vernacular because the vernacular <u>will</u> be used. Relating the vernacular to the set of terms employed in Reports I through III may also assist some readers to better understand the terms and concepts employed in the earlier reports. To the end of relating the important human factors terms to the uncommon terminology of the previous reports, and to the end of discussing some of the apparent inadequacies in current concepts, this report has been prepared.

This report contains twelve substantive chapters. The chapter headings are in each case important words from the vernacular. Within each chapter there is presented first a discussion of the chapter heading. Following this, there is a discussion, term by term, of the important concepts employed in human factors work which are related to the concept identified in the chapter heading. When it is appropriate to do so, these concepts are related to usage in Part A or to other reports of this series. Discussions of techniques related to the concepts are not introduced unless necessary or useful for the purpose of conveying the concept to the reader. The concepts covered in these chapters are the important tools for synthesizing aerospace systems. Some of them are related to aerospace systems as a whole, but the majority of them are important in the design and development of the man-related features of man-machine systems. When it is appropriate, the utility (feasibility) of a concept is discussed in the light of human factors experience in aerospace system development and in the light of the rationale of the simple man-machine development cycle presented in Report I. For the convenience of the reader, a copy of the symbolic model and a brief explanation of it are presented in Part A of this report.

The previous reports have not emphasized the role of basic data in system development and in the development of personnel products. This report places greater emphasis on the role of basic data in the real world of development of man-machine aerospace systems.

Preparation of this report has revealed an important research implication. This implication is discussed in the final chapter of the report.

II. A DEVELOPMENT CYCLE MODEL FOR AEROSPACE SYSTEMS

All of the reports in this series relate to the model of the aerospace system development process that is presented in Report IA. Of all of the reports, the relationship of this one, Report IIB, is most tenuous. In fact, a reader who is interested in the usage of the terms discussed in this report, but who has no serious interest in the development cycle model itself may safely ignore all references to the model and to the specific terms by which the model is described. Therefore, in order not to overburden this report in the series, we refer the reader to the diagrammatic version of the model taken from Report IA and presented in Part A of this report. For the reader who is familiar with Report IA, the diagrams presented in Part A will serve as an adequate reminder of the content of the model so that he need not refer back to Report IA. The reader who has not seen Report IA but who is interested in the model should refer to that report for details.

For the reader who must choose whether or not to refer to Report IA, a few words about that report may be useful. Report IA attempts to present a model of an aerospace system development cycle that will enable the prediction, design, and control of human engineering, human factors, biotechnological, and life support system activities necessary for the successful prosecution of an aerospace system development cycle. The report presents a working vocabulary of approximately forty terms, some of which are referred to in this report, and employs these terms and an associated set of symbols to present a model of aerospace system development cycle at the level of detail given in Figures 1 through 9 in Part A of this report. The report also presents a detailed discussion of the rationale underlying the model. It can be seen from examination of Figures 1 through 9 that the diagrammatic form of the model ignores development errors. Thus, the diagrammatic form is one which assumes that development will proceed without the need for correction and retrofit. Report IA contains a discussion of principles by which this form of the model can be elaborated to take account of errors in system development by means of management actions.

Report IA presents an index model which is a simplified model in eight functions that presents an overview of the entire development cycle model. The diagrammatic form of this model is presented in Figure 1, Part A. Figures 2 through 9 (Part A) present the diagrammatic form of the breakout of each of the functions in the index model. The development activities identified in these figures are defined in terms of their input and output states; the diagrams show the relationships among the activities so defined.

III. PERSONNEL SUBSYSTEM

The two major topics included in this chapter are, first, a discussion of the concepts involved in the definition and development of personnel subsystems and, second, system analysis. The inclusion of the concepts related to system analysis per se within this chapter reflects, to a degree, an aribitary position. System analysis is a broad term that can be applied to a number of the chapters of this report. However, this report is concerned primarily with the concepts related to man-machine systems—and thus is specific to a particular focus toward systems—and system analysis provides the basic context within which personnel-related concepts are developed. Therefore, it was felt that inclusion of the system analysis topic would be appropriate in the first substantive chapter of this report.

Personnel Subsystem

During the past ten years, personnel subsystems have been the focus of wide attention in industry. This attention has resulted from a growing awareness of the contribution to any system made by the human component. Whether he is used solely to maintain an essentially machine system, or to operate on-line system equipment, the human requires human-oriented machine interfaces, training, system-specific skills, and particular kinds of environments. The specification of those aspects of the system that have direct and indirect bearing on the use and performance of the human in a particular system is what is generally meant by the personnel subsystem concept. This subsystem requires a special development organization and consideration just as any other essential subsystem.

As it is currently used, the term subsystem refers to a specific set of elements within a system. However, by extension the personnel subsystem is used to identify particular programs of development within the setting of a system development cycle. Those programs implied by personnel subsystems include the following (after AFSCM 80-3, ref. 3):

1. Definition of the methods, techniques and procedures used to acquire personnel subsystem data and products;

2. Identification of documentation within each phase of the system development cycle that pertains directly to personnel subsystems;

3. Provision for integration of all system development activities with respect to man-machine interfaces and specific human-related requirements, tasks, and system provisions.

From the above, it may be seen that personnel subsystems are a major focal point for the organization of all analyses and data collection relative to human interaction within a system in question. This concept, then, includes considerations of any aspects of man in the system whether the man is functioning as a supportive agent to the system, or is a direct operational agent.

Report Series Relation

In this series of reports, the phrase personnel subsystem is not employed —primarily because the things to which it refers do not constitute a system as the term system is used in this report series. Thus, to use the term personnel subsystem might create confusion as to the intended meaning of the term system. Another reason for avoiding the term personnel subsystem is the general ambiguity with respect to the implications of the term. Clearly, it does not refer to a single set of end products nor to a single process. Variation in the use of the term makes it inappropriate for use where there is an attempt to communicate with precision.

The term used in this series of reports which comes closest to personnel subsystem is personnel products package. The personnel products package is the collection of all of the end products of a man-machine system development cycle which are required because man is employed in the operational system. It includes such personnel products as selected and trained crew members, job aids, human-engineered interfaces, materials to be used in maintaining reliable human performance on the job, and support system means such as life-support system equipment.

System Analysis

System analysis is a term that has been in use in the aerospace industry since its inception. However, as with many terms in general usage, it permits no precise definition by concensus. It has been used to refer to a number of specific analytic techniques in a fashion idiosyncratic to its application. Apart from any general attempt at defining this term, it is operationally defined each time it is used by the nature and kind of analytic techniques subsumed within it. One attempt at precise definition of the term system analysis is as follows: "The discovery and identification of sources of error or variability in a system, the measurement of these errors, and the arrangement of elements to improve system performance." (AFSCM 80-3.) This definition is adequate for many uses of the term; however, it would exclude many current uses of system analysis during the development cycle.

In current use this term is operationally applied to those situations in which several specific analytic techniques are applied to a system. These techniques consist of the following:

1. Requirements and constraints—including the identification and development of mission requirements, performance requirements (of both equipment, support and mission-oriented, and personnel) system constraints.

2. Functions allocation—the allocation of functional processes to men and/or machines. This term is discussed elsewhere in this report.

3. Analysis of design requirements—determination and specification of the system's primary goals in terms of required outputs of the system to be developed.

4. Functions analysis—identification of functional components comprising the system in order to reach the system output state.

5. Man-machine capabilities—determination of the specific capabilities that can be performed by men or machines.

6. Identification of design requirements—determining the parameters and values necessary to choose between alternate means for reaching the system output state (trade-off evaluation).

7. Identification of personnel functions and system reliability—determination of the degree to which personnel have been assigned to functions which they can perform well.

While a particular instance of systems analysis may not include all of the above analytic concepts, it would, as a rule, include most of them. The system analysis concept then does not refer to a particular analytic technique, but rather is itself a collection of analytic goals, each component of which can be performed by several specific means. In the space warranted by this discussion no attempt at completeness or exhaustiveness can be made with respect to listing analytic goals, procedures, techniques that would be nominally included in the concept of system analysis. However, the ones mentioned above are representative of analytic programs currently in use.

Report Series Relation

The term system analysis is not used in these reports because it has been used with such a variety of meanings. Thus the term cannot at present serve as an effective one in precise communication.

IV. SYSTEM REQUIREMENTS ANALYSIS

During the initial stages of system development, the primary focus of effort is toward defining the requirements essential to the most useful exposition and specification of the system. In a manner of speaking, the greatest proportion of effort expended during early system development activities may be seen to be related directly to a definition, specification, and identification of requirements of the system as a whole and specific elements within the system. Certainly, within the context of Air Force system development sequencing, early phases are concerned primarily with requirements analysis in one form or another within the context of system engineering documentation.

The manner in which requirements are identified is largely contingent upon the level of specificity of the system to which the requirements are to be applied. Thus, one may perform an analysis of the requirements of a system qua system by using the broadest functional definitions of the system, and by identifying the needs imposed by the follow-on system (the system in which the reference system is embedded). That is, a system is developed to serve a number of relatively specific needs. Identification of these needs is made most readily by referring to the so-called follow-on system and adjacent systems that the developing system will serve.

Within the developing system itself, requirements may be identified for any given function or subfunction level. Thus, function A may have specific requirements associated with the needs demanded by its associated function B. In general, the history of requirements analysis within the system parallels the development of analysis for that system.

The term requirements is difficult to identify and define in and of itself. It is typically associated with a modifying word, as in <u>system</u> requirements, or <u>mission</u> requirements. Topics discussed within this chapter are, therefore, principally related to the term requirements in association with some modifying word. The topics discussed include system requirements, mission requirements, requirements analysis, and personnel requirements data.

Also included in this chapter, is a discussion of the concepts related to system requirements sequences. This phrase has a variety of meanings in use throughout the aerospace industry. As used in this report, it is taken to refer specifically to what is otherwise known as the development sequence. That is, the manner in which a system proceeds from initial conceptualization to final development. Each agency has, for the most part, derived its own set of partitioning phrases for the development cycle. Discussed in this chapter are the development cycles of the Air Force and NASA. Because the development cycle is, to a large degree, concerned with definitions of requirements, this topic is included in this chapter.

System Requirements

Requirements refer to the essential operational performance of a system, or of its components. Performance in this sense is not the product of a particular means, but rather the functional performance of the system. In general terms, it is a Primitive Need Statement or a set of statements that reflect what a system, or a part of a system, must do. This term may be distinguished from specifications in that specifications are generally related to specific end items; that is, particular pieces of equipment or means to accomplish a particular kind of performance. Although the distinction between requirements and specifications can be made, current usage in the aerospace industry frequently confuses them. An additional term, also confused with requirements, is constraints. Constraints, in this context, should refer only to limitations imposed on the manner in which a system performance is accomplished rather than the nature of that performance itself.

Requirements, in and of itself, is a broad term rarely used in the development cycle of a system. It is more frequently found associated with modifying terms to refer to specific kinds of documentation or analyses. Usual usage is exemplified by the following: task requirements, design requirements, and functional requirements. In each of these cases, some change in the original definition of the term has taken place. Task requirements refer to definitions of the kinds of performance required by human tasks. They are therefore, to a degree, means-oriented in that a man-machine allocation would have preceded any definition of human tasks. Design requirements represent a similar modification of the general definition of the term requirements, in that design also refers to specific means and/or end items. In the case of functional requirements, the term requirements is used in its broad sense.

Establishing system requirements is frequently felt to be the responsibility of the sponsoring agency and is sometimes provided prior to personnel subsystem development. However, for personnel subsystem analysis to provide the most meaningful man-machine allocations and subsequent task delineations, system requirements must undergo a parallel analysis. That is, at each level of system specificity, requirements must also be made more and more specific. At the task level, the requirements specified by task analysis must reflect not only those idiosyncratic to the task, but also those components of the system requirements that are relevant.

It is clear from the above that the initial statements of requirements of a system are extremely important to subsequent system development. Without precise definitions of the requirements of a proposed system, there is little way of identifying what performance the system must be capable of, and what the outputs of that system must be. As a result, determination of the requirements of a particular system is usually the first step in the development cycle. However, it is a step that is frequently imposed on the customer agency rather than the contractor.

Report Series Relation

In the context of this report series, the term requirement has a much more specific connotation. A requirement is specified by identifying a desired output state. There is never a requirement for a means; only for a state. A given requirement is satisfied when a real-world means is used to provide the output state identified in the requirement. Thus one might document a requirement for a particular payload to be in orbit about a planet, without initially specifying the means by which it is to be accomplished.

The source of system requirements is found in close analysis of the needs of the system it is to satisfy. To continue the above example, the need may be for a practice in performing docking maneuvers. From the statement of that need, a requirement for a particular payload in orbit may be generated.

Requirements Analysis

The term, as it is used today, has both general and specific meaning. Generally it refers to any of the techniques used for determining the broad requirements of a system to be developed, as well as specific characteristics of means selected to meet these requirements—as would be necessary in specifying lower levels of functions analysis. Requirements may be identified at virtually any level of specificity. Any technique that has as its goal the identification of these requirements may be properly called requirements analysis. More specifically, however, this term has come to be applied, in Air Force usage, to a specific type of method used in association with, and as part of, a general functions analysis. This specific technique is embodied in the use of a requirements analysis sheet (RAS) that presents a verbal description of a function together with the constraints imposed on the performance of that function, and the interactions of that function with other functions. In this more limiting definition of requirements analysis, the purpose of analyzing system requirements is to determine the specific functions the system must perform. In this context the requirements refer to the requirements of the system in question for particular allocations of men and equipment.

<u>Requirements analysis</u>, as it is usually applied in current aerospace development systems, may also refer to other portions of a functions analysis. Within the framework of functions analysis, the term is associated with several others: mission requirements, performance requirements and system constraints.

<u>Mission requirements</u> are broadly stated functions that the system must perform, viewed, in a sense, as end items. For example, the injecting of a manned space vehicle into orbit, or the launching of a rendezvous target vehicle into orbit would be requirements for missions associated with Gemini flights.

Performance requirements are details of the system's mission requirements. As a rule there are two types of performance requirements, operational and support. Operational requirements are concerned primarily with the active performance of the mission, while support requirements are those related to the equipment and events concerned with preparation and maintenance of the operational capability of the system. The modification of a mission requirement by appending performance specifications—for example injecting a space vehicle into orbit and appending the altitude of the orbit and the velocity of the vehicle while in orbit—would result in performance requirements.

System constraints are limitations imposed on the manner in which the design of the system takes place in terms of factors originating from outside the system being developed. For example, the funding available to develop the system, the nature of personnel available for manning the system, the period of time in which the system may be developed, are all system constraints.

Report Series Relation

Requirements analysis, as a term, is used in this series of reports. However it refers to a slightly different concept than the above definition.

In these reports the term is applied to the first function in a development cycle. The principal input to this function is a Primitive Need Statement; its output is a document which specifies an operational system requirement. The requirements analysis may be implemented by the customer in response to his own Primitive Need Statement, or it may be carried out by an agency hired to act for the customer. The essential steps of a requirements analysis are as follows:

1. The follow-on system of concern to the customer is defined.

2. The Primitive Need Statement is considered, and, if necessary, it is revised to identify the specific problem to be solved within the system of concern to the customer.

3. Agreement is achieved with the customer with respect to how to measure success in solving the identified problem within his system of concern.

4. Input states to the follow-on system which may solve the identified problem are hypothesized.

5. Confirmation exercises are undertaken to determine what input state to the follow-on system will best solve the identified problem. This step may, for example, involve construction of a model of the follow-on system which will permit examination of its performance given various input states.

6. Further study of the follow-on system is undertaken as required in order to prepare an operational system requirement document whose main purpose is to identify the output of the needed system. Thus a requirement is generated for an output state to be provided.

Personnel Requirements Data

The personnel subsystem is the context within which analysis and data collection of information about, and for, the personnel utilized in manning the system to be developed are integrated. The results of these analyses and data collection appear in the form of the personnel requirements data. That is, personnel subsystem refers to various specific elements of the system. For those particular elements of the system, various analyses and data collection activities are performed. The results of the data collection and analyses are in part the personnel requirements data. Those data related to determination of the requirements for and about personnel to be used in the system—such as training, environmental constraints, man-machine allocations—are the data of concern here.

Report Series Relation

There is no term in these reports that is logically or functionally equivalent to personnel requirements data.

System Requirements Sequence

With the complexity, cost, and time requirements associated with the development of aerospace systems today, a great deal of sponsor-contractor interaction is necessary. Organization of this interaction—in fact, organization of the entire development cycle of a new system—is the function of the system requirements sequence. There have been several attempts at an organizational scheme. Perhaps the most public scheme now in use in the aerospace industry is that developed by the Air Force as part of their 375 management series (refs. 1, 2, 4, 5, 6, 7, 8, 10).

This development scheme is concerned with the organization and control of data required to support the life cycle of a new system. In the Air Force scheme, the life cycle is divided into four phases: Conceptual, Definition, Acquisition, and Operational. The Conceptual phase has as its objectives the recognition and definition of requirements for future systems, conception of systems that potentially satisfy the requirements, and stimulation of development that make technically feasible the satisfaction of the requirement. This phase results in a thoroughly defined set of system requirements, a technically feasible system concept, and a preliminary system design. The phase may be initiated by the government or by contractors, although it is typically a sponsor-related activity. To a degree this phase is analogous both in terms of objectives and potential outputs to Phase A and part of Phase B of the NASA sequence (ref. 12): the Advanced Studies phase and the Project Definition phase. It also corresponds to the Concept Formulation phase of the DoD (ref. 11).

Although it is difficult to make exact comparisons, it appears that Functions A and B in the index model given in this report correspond to Phase A of NASA, and that Function C in the model corresponds to Phase B of the NASA.

The second important phase in system development for the Air Force is the Definition phase. This phase has as its general objectives the definition of cost scheduling and technical design requirements of the program. It is usually viewed as a set of three subphases. The first subphase (1-A) is the preparation for contractor definition, and is a synthesis of information derived from the first phase and results in an RFP. The second subphase (1-B) starts with the award of a contract to one or more contractors and covers the task of defining all aspects of the program in terms of performance, design requirements, and time and cost estimates. The third and final subphase (1-C) is for sponsor review and decision. During this subphase, the sponsor evaluates the contractor reports and makes recommendations for acquiring the system in question. For the most part, the Definition phase is the focal point for the development of system engineering documentation in general, and personnel subsystem data in particular. It is during this phase that initial determination of functions, allocations, manning, training and training equipment, and maintenance concepts are derived. Since a major goal of the Definition phase is the determination of cost estimates for the acquisition of the system, it may be seen that specification of systems analysis (particularly to the man-machine allocation level) is essential in order to determine the contractor end items (CEI) necessary to make cost estimates. Frequently, the second major cost item is the training and training equipment. Consequently, during this phase a great deal of effort is focused on those analyses concerned with training. At the end of this phase sufficient information is presented to the sponsor to permit determination of which contractor should be permitted to develop the system in question to its operational stage, the cost involved in such development, and the feasibility and potential system effectiveness of such a system. This phase is apparently analogous to the latter part of Phase B of the NASA sequence.

The third phase in the development of the system is, for the Air Force, the Acquisition phase. This phase begins with the award of contracts to an industrial organization and ends during the operational or fourth phase when the system and management responsibility for the system is transferred to the using command. This phase includes detailed design of the system, construction of the system, and various levels of testing directed toward determining whether the system is meeting the proposed performance standards. During this phase the contractor delivers specific contractor end items to the sites on which they are to be operational. Various tests are performed on the end item to insure its adequacy and, as a general rule, on a site-by-site, item-by-item basis. As each portion or item of the system is accepted by the customer, that item becomes operational. The acquisition terminates when all elements of the system have been delivered and responsibility is transferred to the using command. This phase apparently corresponds to Phase C and to part of Phase D of the NASA sequence. In the NASA sequence, Phase C is entitled Design and Phase D, Development/Operations. That part of NASA Phase D concerned with operations is best equated with the Operational Phase of the Air Force (see below). NASA Phase C and the Development part of Phase D correspond to Functions D, E, F, G, and H in the index model given in this report.

The final phase of system development in the Air Force scheme is the operational phase. In this phase, delivery of end items, and testing and final acceptance is completed. This phase is initiated when the first operating unit is accepted by the user, and terminates when all contracted aspects of the system in question have been accepted by the using command. Since in complicated systems end items are produced sequentially, this phase can overlap with the previous Acquisition phase.

The above phases in the life cycle of a system to be developed are, among other things, a data management organization. As a rule, categories of data are standard throughout the four phases; however, the particular analyses and specificity of data involved varies from phase to phase, as does the use to which the data is put.

Comparison of the NASA development sequence with the Air Force development sequence indicates that while the total scope of each is quite similar to the other, the manner in which development activities are apportioned to specific phases differs widely. These differences in part reflect the different needs of the two agencies. Products (systems) provided to the Air Force by the aerospace community frequently involve many copies of each system. That is, in proposing a development system for an air-to-ground missile, a large number of missiles are to be ordered during the final Acquisition phase. NASA's requirements are more frequently concerned with a highly complex system. However, the number of units of that system is frequently much smaller than that required by the Air Force. That is, in requiring the development of a man-rated orbital capsule such as the Gemini, NASA requires only a relatively small number of these units. The Air Force, in ordering air-to-ground missiles is concerned with hundreds or thousands of units. As the Air Force becomes more involved in highly complex space vehicles as, for example, the MOL program, the similarities in requirements between the two services become much greater.

In addition, the Air Force scheme reflects a strong need to clearly assign responsibility between the customer and contractor. For the most part, the Air Force mans, and has sole responsibility for, their operational systems. NASA's development cycle, on the other hand, appears to place a great deal of emphasis on agency/contractor interactions and co-working relations. This interaction is evidenced in all phases of the life cycle.

Report Series Relation

This entire report series is concerned with the topic of system development as a process. The report in this series which best describes how the process is conceived is Report IA, A Simple Model of a Man-Machine System Development Cycle.

V. FUNCTIONS ANALYSIS

The term functions may be found in virtually every science and discipline. Regardless of its role in other applications in the scientific community, it certainly plays a key role in systems analysis for human factors research. However, merely because the term is a very important one in human factors research in general and system development in particular, and merely because it is used frequently, does not necessarily mean that the term has been precisely defined nor consistently used throughout the aerospace industry. In some cases discrepancies between and among uses of functions and functions analysis reflect more than just minor shades of differences; rather, they represent gross changes in focus and importance.

Traditionally, the term has been applied as the label for the black box of engineering drawings. That is, in attempts to diagram or block flow a description of a system (as part of a developmental analysis), the term function has usually been applied as a label to the blocks thus identified. When the blocks have been identified, lines indicating interrelationships among blocks are drawn to complete these diagrams. Very little attempt is made to specify the precise nature of these interconnecting lines. They may be lines of communication, data flow, or indicate direction of a process. At the other extreme, recent investigation of functions and functions analysis has led to a high degree of specification of the lines interconnecting the blocks, with a parallel devaluation of concern with precise labelling of the block itself. In these latter cases, the process of defining the system is seen to be most usefully performed by identification of the interconnecting lines or "states"[1] rather than the block itself.

The principal purpose of this report was not to provide a critical analysis and comparison of the terms currently used in the aerospace industry. Rather, the goal of the report was only to present the terms and definitions of terms and concepts currently in use, and relate these terms to the concepts

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[1] Cf. "state" Report IA.

presented in the other reports of this series. Consequently, the definitions of functions and related terms represent only those in common use, with no attempt to be complete in presenting every possible definition.

Three major topics are presented in this chapter: functions (personnel), functions analysis, and design requirements. These three terms are seen as the major focal points for functions analysis concept formation.

Functions

Functions are generally considered to be the major components (or subsections) of a system. These components are usually, but not necessarily, expressed as operations or processes rather than specific equipment or techniques. The nature of the functions identification within the system is, in part, contingent on the reason for making the identification. If, for example, the need is to identify contributing subcontractors in the construction of an operational system, functions may be identified on the basis of development and manufacture of each of the associated subcontractor subsystem responsibilities. If the purpose of the identification is to describe a specific space vehicle, functions may be associated with individual subsystems or components of the system as, for example, launch site, ground stations, boost vehicle, orbiting vehicle. In the case of a complex space system, major functions may be identified by classification on several dimensions. An example of this would be the major functions used to describe an orbiting laboratory consisting of training, personnel selection, launch vehicle, orbital configuration, reentry vehicle, ground support equipment, ground command equipment. In this last example, major functions were identified to meet the needs of several purposes. In industry, particularly when major systems are being developed, such mixed schemes of function identification are frequently used. By doing this, the needs of personnel development, as well as equipment construction and contractor responsibilities, can be incorporated into one model.

Documentation of functions identification is usually performed in the form of block diagrams. The standard technique is that of function flow block diagramming, although other diagramming techniques have been used on occasion.

This block diagramming technique is one in which each function is assigned a particular block and interconnecting lines are used to show the relationship among the identified functions.

Report Series Relation

The term function is used with special meaning in this series of reports. It is employed despite the fact that it is used in the open literature with a variety of meanings, primarily because the present precise usage has developed over time out of a less precise usage which originally had connotations similar to those in the vernacular.

For the purposes of these reports, a function is a special kind of symbolic statement. It includes an input state, and an output state. There is a point in time associated with the input state, and a later point in time associated with the output state. Further, there is a probability associated with the output state which assumes that the probability of the input state is one. Functions are "implemented" by means, that is, by real-world processes, which can be set in correspondence with functions. A complete intuitive definition of the term is given in Report I and a complete, precise definition is given in Report IB.

Functions Analysis

Identification of functions represents the major component in conceptualizing the system to be developed. Analysis of these functions is performed in order to determine how each function can best be performed in the system, and to consider feasible alternative combinations that will lead to optimizing the output of the system. While there are a number of component analyses and procedures that enter into the analysis of functions, the use of any one or combination of these procedures is largely contingent on the specific application involved. Functions analysis is embedded in the process of systems analysis and as such has associated with it concomitant analyses of system requirements, constraints, and specifications. In addition, as a part of systems analysis, expensive review and development of criterion measures for system effectiveness should also be included. Each of these associated analyses make their contribution to the analysis of function.

As performed currently in aerospace system development, functions analysis is comprised of two major tools which operate hand-in-hand. These tools are functional flow block diagramming, and verbal descriptions of the contents of each major identified block (RAS). Within these verbal descriptions, whether they are called requirement allocation sheets or some other term, are identified the component activities within the function, training requirements, specific constraints, design concepts, and an estimate of the contribution to system effectiveness.

The verbal descriptions are predicated onthe function flow block diagramming. When the descriptions have been completed, the description of the function, in which component functional activities and requirements have been identified,can then serve as block identifiers for the next lower level functional flow block diagram. Thus, by alternating between functional flow block diagrams and verbal descriptions of the functions or blocks, each iteration carries the functions analysis to lower and lower levels of abstractness and to greater specificity. This iterative process is continued until at some point concrete means decisions, i.e., man-machine allocations, can be made.

Functions analysis, then, is essentially any technique wherein an abstract system, defined in terms of output state requirements, is subdivided into smaller elements of performance and ascribed functional means, rather than physical means. The primary object of functions analysis is to analyze the system means conceptualized at the next higher stage of development, and to delineate requirements and constraints which become new design problems for the next lower level.

For the personnel subsystem, it may be seen that functions analysis is at the nexus of many—if not most—of the analytical techniques employed within systems analysis. That is, requirements analysis, human engineering considerations, identification of man's capabilities, specification of equipment capabilities, all relate to and are predicated upon the functions analysis process. Unless the functions analysis gives appropriate consideration to each contributing datum, the resulting man-machine allocations cannot be considered optimum. Task analysis, training equipment identification, and design specifications are all contingent on the adequacy of the functions analysis.

Report Series Relation

The term functions analysis is not employed in this series of reports as a formally defined term. However, a term which is defined—partitioning—is, in one sense, similar to functions analysis. Both functions analysis and partitioning are operations which result in an expression of the system of concern in terms of a larger number of component functions. In the case of partitioning, the result is always a set of functions and their relationships in which each function is defined in terms of input and output states in the same manner as that employed to identify the functions that were partitioned. Thus, the result of partitioning is a new set of symbolic function statements.

Design Requirements

In the current systems literature, a variety of definitions appears for the term design requirements. Differences among these definitions represent changes in scope and focus rather than substantial changes in direction of focus. That is, the distinctions among these definitions represent emphasis on various levels of specificity rather than a major change in the substantive content of the definition. At the systems level, design requirements are defined as the specification of system performance and are general specifications establishing the requirements and criteria applicable to all system equipment. Such specification has major utility and suitability for further technical development and segregation of contract responsibilities. Eventually these requirements, or system specifications, present the total requirements for system design and development including test requirements. During initial system development these requirements are not considered fixed, but rather must reflect all changes resulting from major decisions regarding system performance and design.

At a more specific level, design requirements may be defined as that portion of the systems analysis produced by requirements allocation. This allocation is an analysis of each function or group of functions depicted on functional flow block diagrams. Considered under design requirements for that analysis are the function description, specific design characteristics, design constraints, operability or effectiveness, and interface requirements.

Function descriptions specify the objective of the function, the activities associated with performance of the function, and the duration of the function in sequential order (timelining). Specific design characteristics specify the input/output performance values, allowable quantitative tolerances, and maintenance requirements of the function. These characteristics are defined as requirements and limitations imposed by the function and are derived from individual elements of the function. Design constraints are defined as external functional requirements and limitations which constrain or impact the design for the function being analyzed. Examples of constraints include time, power, weight, physical dimensions, environment, and human performance capabilities and limitations. Operability or effectiveness includes measures relating the performance of the function in question to the overall system-effectiveness model. As a rule, effectiveness requirements are specified in at least four categories such as reliability, safety, maintainability, and transportability. Interface requirements refer to external function and technical requirements imposed on other functions or equipment, or imposed by other functions or equipment which do not constrain the design of the function being analyzed. These interface requirements can be, and frequently are, shown as lines on function flow block diagrams connecting the function in question and its associated functions.

It may be seen from the above that the process of specifying design requirements is one of starting with specifications on the system level—usually provided by the customer—and in the process of functions analysis, developing more and more specific requirements. However, it should be obvious that the degree to which specific design requirements are compatible with initial system requirements is determined by the initial development of the functional relations to meet the requirements imposed by initial conceptual design of the system, and determination of system requirements.

Report Series Relation

In the current series of reports, a function definition is in terms of input and output states and probability of output. Thus, a function definition might be called a design requirement. However, the term design requirement is used in common practice with other connotations. Thus, design requirement and function definition are not interchangeable.

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VI. DESIGN CONCEPTUALIZATION (MEANS ALLOCATION)

Design Conceptualization has come to mean the methods, tools and concepts involved in the decision to allocate functions to specific equipment and/or humans. One may distinguish between a functional description of a system—the conceptual manner in which the system is to operate—and a description of the equipment and personnel specified by the system to provide that performance. This latter specification of personnel and equipment is usually termed means in current usage. This chapter is concerned with the concepts related to the decision point at which the system designer makes the transition from functional descriptions of the system to the means description. This decision-making area is commonly referred to as means allocation.

Taking means allocation as a central theme for the chapter, four major terms are discussed: functions allocation, cost effectiveness, system constraints, and personnel equipment data. For the most part, these terms and the concepts implied by the terms may be related to other areas of activity within the system development cycle. However, they are most commonly used within the context of means allocation.

Functions Allocation

As it is generally used in the aerospace industry, function allocation is the process of assigning system performance to personnel, equipment and facilities in such a way as to maximize the effectiveness of the system. This allocation process is also called man-machine allocation, or means decisions. In performing this allocation, consideration is given to characteristics of man and machines so as to maximize the utility of both the man and equipment components. Functions allocated to equipment are later analyzed and detailed to permit identification of specific contractor end items for initial hardware design. Functions allocated to human components establish a basis for identifying specific elements of human behavior and for analyzing the tasks, procedures, training and selection necessary. Generally stated, the goal of functions allocations is to establish the design requirements of the system.

Typically, the allocation process comes after the iteration of functions analysis, via function-flow block diagramming and requirement-allocation analysis. Each iteration of the analytic technique increases the specificity of components identified. This is done until particular requirements, constraints, and specifications have been produced to permit precise allocation of the process included within the function to men or equipment. At such a point, either task analysis is initiated or, in the case of equipment-only allocations, design sheets are begun. The total system is divided into smaller elements of performance by analyzing the requirements constraints to determine required performances.

The term functions allocation is frequently associated with the specific process of assigning means, or a combination of many means, to an individual system element. The term design conceptualization is sometimes used rather than functions allocations primarily because the latter may be more restrictive. The term means or function allocation is associated with the specific process of assigning means; design conceptualization is used primarily in an attempt to broaden the scope of the allocation process. Design conceptualization is defined as the development of the design concept.

Report Series Relation

In this series of reports, it is demonstrated that functional specification must precede means specification. This being the case, after a function has been specified, the problem of the designer is to assign a means <u>to the function</u>. This process may be called means allocation.

In some cases, the process of means allocation will result in the determination that the system under design will include general purpose means such as humans, computers, power supplies and the like. Whenever a general purpose means is called out (especially a human) and is justified in terms of overall system cost and quality, then it is usually highly desirable to take full advantage of the general purpose means by loading it to capacity—that is, by assigning to it responsibility for carrying out functions other than those which gave rise to its selection. This process of allocating functions to an already identified means may be called functions allocation. Thus, functions allocation, as it is used in this series of reports, is a process which is, in a sense, the inverse of means allocation, and it is employed only when general purpose means have been justified for inclusion in the system under development.

Cost Effectiveness

Generally speaking, there are three basic levels of cost-effectiveness analysis. They are: (1) selection of mission, (2) selection of competing systems, and (3) selection of optimal resource use.

The first level is typically performed by the customer rather than the contractor. The output of this analysis is a statement of what the program is to accomplish in terms of output requirements for the system to be developed, and the conditions and geographical locations within which the outputs are to occur. The results of the first analysis should define what is required to be done rather than the means employed to accomplish it.

The goal of cost-effectiveness analysis is to provide for the optimum combination of system elements such that the system requirements will be met with a minimum expenditure of cost and a maximum effectiveness. This optimization process takes place during the third mentioned level of cost-effectiveness analysis, and consists primarily of synthesizing alternate means of meeting stated objectives, evaluating them, and selecting the combination which secures the most favorable cost and effectiveness relation. Integral to the concept of cost effectiveness is a concern with determination of appropriate parameters for evaluating various system means. Table I shows examples of cost-effectiveness criteria in various areas of endeavor. It may be seen from this table that the nature of endeavor determines, to a large degree, the kind of criteria applied.

The capacity to optimize the system on any criterion (or criteria) is contingent on the availability of alternate means of meeting requirements. Alternates include specific means, design approaches, and techniques or changes in concept which can be used to meet the stated system requirements within the constraints imposed by the development system. Requisites for initiating

TABLE I

EXAMPLES OF COST-EFFECTIVENESS CRITERIA
(After WSEIAC, Final Report of Task Group IV, ref. 9)

Criterion	Area of Application
Buildings	cost (dollars) per square foot
Transportation	dollars per passenger mile
Communication	dollars per message unit
Power	dollars per kilowatt hour
Gas (natural)	dollars per cubic foot
Farming	dollars per square mile
Launch vehicles	dollars per pound payload in orbit
Orbital vehicles	dollars per hour of successful on-orbit operation

cost-effectiveness analyses are specified system requirements, constraints and environmental conditions within which the system is to perform, and feasible alternatives for means, procedures and techniques in the development of the system. The general methodology of this analysis is as follows.

The first step in organizing data necessary to construct cost-effectiveness models and perform the analysis is to determine the criteria to be incorporated within the cost-effectiveness model. While every attempt is made to quantify the criteria selected and to choose quantifiable criteria, the choice of criteria is frequently influenced by judgment. Generally, system analysis proceeds concurrently with cost-effectiveness analyses and specifically with the determination of criteria to be used in cost-effectiveness analysis. Much of the system data produced by the system analysis impacts on and has relevance to the formulation of cost-effectiveness criteria.

The second step is the identification and synthesis of alternate means of meeting system requirements. Often the focal point for identification of alternates is the functional level immediately preceding the man-machine allocation level. While at this level no specific means have been determined, requirements for design and design conceptualization have taken place. Therefore it is an appropriate level in the analysis to suggest and identify alternatives that have potential value. Within the context of this level of analysis, alternatives which may be suggested can immediately be fitted to the requirements called out by the system.

The next step in performing cost-effectiveness analysis is to determine, for each alternative, the significant variables which must be considered in order to optimize alternate choices. Clearly, although there are many potential variables, only those which are significant to cost, resource availability, or system effectiveness should be chosen. Typical variables influencing cost-effectiveness evaluation of alternatives in a space system are cost, weight, payload carried, mission duration, time requirements, reliability, maintainability, and safety.

Both cost and effectiveness vary as a function of a number of parameters interrelated in highly complex fashions. In order to coordinate the parametric corelationships and exercise the variable nature of cost effectiveness, these parameters identified in the previous steps are integrated into a mathematical model, or set of mathematical models. The models may take a number of forms. Those most frequently recommended are the profit, cost-effectiveness (level) ratio, and cost-effectiveness (long-term) ratio models. There are additional models, as there are variations of these models, used currently. However, those named above are the most frequently recommended models for establishing basic cost effectiveness. For any model used the general characteristics must be as follows:

1. All assumptions required for the model must be stated explicitly and supported by empirical evidence.

2. All major variables to which the solution is sensitive should be quantitatively considered. Nonquantifiable variables may be accounted for by modification of the solution rather than direct incorporation into the model.

3. The model should, to the degree possible, represent the true situation. If this is impossible for all except subparts of the model, the subparts may be pieced together through appropriate modeling techniques as, for example, by use of various simulation procedures.

4. Probabilistic uncertainties existing in the model as a result of system alternatives, or uncertainties with respect to the nature of the operational characteristics of the system should be investigated by some statistical technique such as risk analysis, functions of random variables theory or Monte Carlo techniques.

5. The ultimate test of a cost-effectiveness model is whether it results in the selection of the best system. There is some question whether this requirement of a cost-effectiveness model can ever be met objectively. However, the answers to certain questions which may be posed to the model can disclose weaknesses that may be corrected.

Some questions which may be asked that suggest, if not actually test, the validity of the model are: (cf. WSEIAC Final Report of Task Group 4, ref. 9)

1. Consistency—Are results consistent when major parameters are varied, especially to extremes?

2. Sensitivity—Do input variable changes result in output changes that are consistent with expectations?

3. Plausibility [1]—Are results plausible for special cases where prior information exists?

4. Criticality—Do major changes in assumptions result in major changes in the results?

5. Workability—Does the model require inputs or computational capabilities that are not available within the bounds of current technology?

6. Suitability—Is the model consistent with the objectives: i.e., will it answer the right questions?

Throughout the above discussion no specific reference to personnel subsystems was made. However, it should be obvious that cost effectiveness may be intricately involved with the development of personnel subsystems, particularly with respect to the allocation of functions to personnel or equipment.

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[1] This might be extended to include compatibility with existing models.

However, for such allocations to have a major role in the construction of appropriate variables and parameters within the cost-effectiveness model, human performance functions must be associated with quantitative system-effectiveness measures. To the degree that such measures are not usually applied in current developing systems, the impact of human performance and the personnel subsystem development on the total cost-effectiveness trade-offs of the system must necessarily be slight.

Report Series Relations

Terms such as cost effectiveness, cost utility, and cost benefit are not used in this series of reports except in general discussions where precision of usage is not required. Where precision is required, the coordinates employed are named Cost and Quality. As in the case of cost effectiveness, the Cost coordinate is a resource coordinate. It is in the second (Quality) coordinate that a specific difference in implication is seen. The Quality score associated with any system solution is determined by considering external effects of the system rather than the internal attributes. Thus, the formula for obtaining the Quality score for any system is independent of the means by which the system is implemented. In the case of effectiveness (including system effectiveness and military effectiveness), measurement frequently gives specific consideration to the means employed and results in a formula that cannot be used to measure the goodness of vastly different alternative systems, all of which are candidates for solving the same problem.

For a complete definition of Quality score and the concept of the Cost, Quality space, see Report IA.

System Constraints

System constraints are the environmental, resource, cost, and time limits imposed on system design by the state of the art or by the procuring activity. Identification of these constraints is typically a part of the analysis of system requirements. As a general rule, the constraints are derived from sources external to the system in question. That is, these are not constraints imposed by a particular man-machine allocation; they are constraints imposed by specifications of the system context—the cost, resource, political and managerial milieu.

Report Series Relation

In this series of reports, a constraint is defined as an intentional limitation on the freedom of the designer to select system means.

Personnel Equipment Data

Personnel equipment data (PED) are centrally controlled task and equipment information that define the personnel and equipment interface within a given development system. It is a systematic program for collecting and analyzing data (and only that data) which will support the personnel subsystem functional areas. The PED does not collect or generate additional systems data; rather, it is a context for analysis of existing system engineering data in terms of the data implications to human performance.

These task and equipment data are used to:

1. Develop safe and effective equipment designs;
2. Provide basis for training plan development;
3. Develop performance criteria; and
4. Provide basic information to support development of manning requirements.

Information provided within the context of task and equipment data is not intended to duplicate other data provided by system engineering documentation. Rather it is a label applied to particular uses to which previously obtained data may be put.

Report Series Relation

There is no special term used in this series of reports that is equivalent to personnel equipment data. In fact, in the layout of the development cycle model a somewhat different grouping of data relevant to interfaces is employed. In the model, interface data include personnel/personnel interface data as well as personnel/equipment data, and the solution of the interface problems so defined is considered within a single development activity. On the other hand, in the model, interfaces between operator performance and prime equipment are considered separately from interfaces between maintenance technician performance and maintenance equipment. The separate consideration of these two classes is necessary because the different classes of interfaces are defined at different times in the course of development.

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VII. PERFORMANCE SPECIFICATIONS ANALYSIS (TASK ANALYSIS)

Subsequent to an analysis of the functions, requirements, and means allocation of the system being developed, is the analysis of the tasks identified for the personnel to perform. These tasks include both maintenance and operational activities of the human components in the system, as well as any support or back-up activities to be provided.

Task analysis per se is a term applied both to a concept—in the sense of identifying a type of analysis that must be performed during the system development process—as well as a set of techniques, methods, and tools for providing this analysis. In this report the interest is primarily in the concepts related to task analysis rather than the specific tools that might be employed to provide the analysis. The tools are in and of themselves interesting and warrant discussion in a methodologically-oriented report, rather than in a conceptually-oriented report such as this.

Two major topics are discussed in this chapter. One is a broad discussion of task analysis. The second is a discussion of the qualitative and quantitative personnel requirements information (QQPRI) serving as a general context for the task analysis. QQPRI is a broad concept covering a variety of data. However, most of the basic data supporting QQPRI development is generally obtained from one form or another of task analysis.

QQPRI

Qualitative and quantitative personnel requirements information (QQPRI) is personnel subsystem data used to plan the kind of personnel needed in the system, the skills and training required, and the performance required of these personnel. It identifies the man-machine interfaces in terms of operation, as well as the nature, scope and kind of maintenance activities imposed by the system design. This term had its origin in USAF documents but has come to be generally applied in the aerospace industry. It differs from personnel subsystem planning primarily in that it focuses on the systematic identification of job classifications required by the system, identification of organizational tables and manning requirements, and on training aspects of the system. As a rule QQPRI does not produce detailed task equipment data. These data are results of other kinds of analyses and would be developed during the preparation of QQPRI only if adequate data have not already been made available. QQPRI is a broad term which covers a number of specific information elements. These are:

1. System description—a brief functional description of the purpose of the system in question. Included are operational characteristics of the system and concepts underlying operations and maintenance. Description of anticipated operation and system support is illustrated by mission profiles, flow diagram, etc.

2. Summary of maintenance and operations—a detailed analytical summary in time sequence of all major jobs required to operate and maintain the system. This summary identifies both maintenance and operations personnel by number and by service job classification.

3. Position descriptions—a report of the personnel required to operate, maintain and control the system by service specialty code covering the duties and responsibilities of each position. Generally, a position in this sense means each operator or maintenance personnel required by the system, irrespective of the jobs and tasks performed by the system. That is, a given subsystem may require 30 or 40 tasks to be performed and specify only five individuals to perform those tasks. Each person in the course of a normal work shift is considered a position. Position descriptions include a list of the principal duties and tasks associated with the position, the aerospace ground equipment used in accomplishing maintenance tasks or system equipment which must be operated by operational personnel, the amount of time required to accomplish each duty or task, the location of each task performed and an estimate of how frequently each duty and task must be performed, and the proficiency level at which each task must be performed.

4. Preliminary manning estimates—the manning concept for the system is presented, in which all conditions considered in preparing the estimates, such as operations and maintenance criteria and any special conditions, were identified. In addition, actual manning estimates are presented in tabular form in manning tables and preliminary organizational diagrams.

Report Series Relation

It can be seen that this concept includes a large variety of data and design outputs generated at different times in the course of a man-machine system development cycle. Some of the data included within the collection called QQPRI are truly necessary for the prosecution of a successful development cycle; other data may only be of interest. In this series of reports there is no time at which it is necessary or useful to refer to the specific collection of data implied by the term QQPRI, and therefore the term is simply not employed.

Task Analysis

Task analysis is a term that has been used for the past 15 years to identify a particular kind of analysis or sets of analyses. Although the term is used frequently, there appears no general industry-wide agreement as to the precise definition of the term, nor the specific steps to be taken in completing such an analysis. The official Air Force definition of task analysis is provided in AFSC Manual No. 80-3 (ref. 3), and is . . .

> . . . an analytic process employed to determine the specific behaviors required of a human component in a man-machine system. It involves determining, on a time base, the detailed performances required of man and machine, the nature and extent of their interactions, and effect of environmental conditions and malfunctions. Within each task, behavioral steps are isolated in terms of perception, decision, memory storage, and motor outputs required, as well as the errors which may be expected.

While other workers in the field define task analysis in slightly different ways, the Air Force official definition is probably as good a representation of the definition as can be found.

Within the context of the above definition, task analysis follows directly from functions analysis. By the conclusion of the functions analysis, man-machine allocations have been made. A further detailing of the activities performed by the man components of the system are reflected in the task analysis. A feature of all task analyses is a statement of the task itself. This is usually given in terms of an action verb description of what the operator is required to do, such as adjust equipment, analyze data, assemble equipment, calibrate equipment, etc. Additional categories of information are also obtained as part of the task analysis. Categories frequently found in task analyses are as follows:

1. Ambient environment—This refers to the nature of environment in which the task is performed, and as a rule ranges from optimum (that is, optimum on all temperature, pressure, humidity parameters affecting the human) to not acceptable without protection.

2. Equipment characteristics—This refers to the nature of interfacing equipment with which the operator will have to perform. This dimension usually varies from equipment making no unusual demands upon the human capacity to design requiring performance at the limits of human capabilities.

3. Mental demands—This category, or one comparable to it, implies the measure of mental or intellectual demands imposed by the task. It varies from small to extensive, and is meant to include tasks that are essentially highly physical with no active mental participation required, to those that require a high level of mental effort such as performing mathematical computations in one's head, extensive decision making, or critical reasoning.

4. Physical demands—This category relates to the demands imposed on the operator by the task in terms of physical requirements. As a dimension it ranges from small or none to extensive demands. Examples of this might be those physical demands of sitting at a desk for eight hours a day versus those requiring extensive use of shovels, or running, etc.

5. Hazard exposure—Refers to the nature of hazards to which the operator would be exposed in the course of performing this task. It ranges from none to extensive hazard. Examples might be monitoring a mission console on a land base versus performing extravehicular activities in orbit about the moon.

6. Task criticality—Refers to the impact of the task on the system-effectiveness model. It ranges from noncritical to inoperability of the system.

Additional categories frequently used in task analysis require information about the nature of job classification of the individual selected to perform those tasks, the training requirements imposed by that task, and the skills and knowledge required by that task. In some instances, estimates of task performance time and performance frequency are also called out during task analysis.

As mentioned, there is no commonality in use of procedures to perform a task analysis. In many cases the nature and detail of the task analysis is fitted to the requirements of the system itself or the contractor performing the analysis. In some cases task statements are derived by a continuation of the functions analysis technique, while in other cases functions analysis is terminated as soon as man-machine allocations can be made and, on the basis of man-allocated functions, tasks lists are prepared. In many cases, particularly in the development of large systems, tasks or task statements have their origin in the requirements allocation analyses performed in conjunction with function-flow block-diagramming techniques. To further complicate matters there is no common acceptance, specification, or definition of precisely what is meant by a task. In the literature of systems analysis, one may distinguish tasks, procedures, and steps. However, while one researcher may propose an empirical distinction among these terms, the distinctions will not necessarily hold across other task analyses performed on different systems.

The contribution to systems engineering made by task analysis is critical to further development of training requirements, man-machine interface design requirements, and assessment of time requirements to perform. Consequently, the incompatibility among and between procedures for performing task analysis imposes a severe limitation on the degree to which systems may be compared with respect to human performance. As a simple example of this, task analysis may be either stimulus- or response-oriented (although the response orientation is far more prevalent). The stimulus orientation approach is to determine the demands for personnel performance. This approach is valuable for developing training equipment which imposes demands on the trainee which are functionally equivalent to the operational situation. The response orientation approach is to determine and document the performance actions. This approach is valuable for human engineering and the development of job aids. Comparison of a stimulus-oriented and response-oriented task analysis, however, for different systems is virtually impossible.

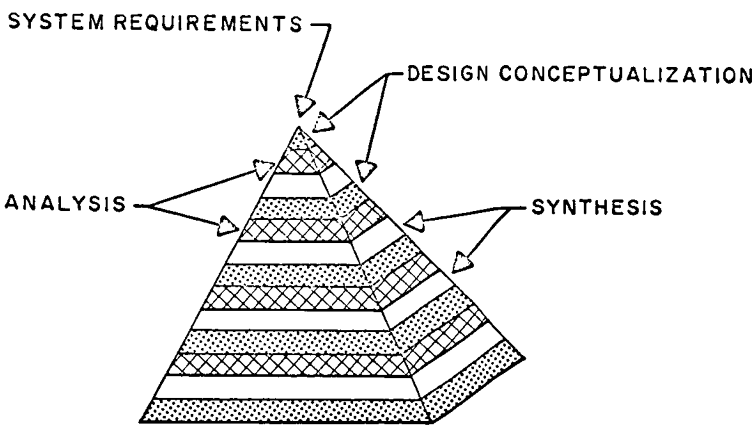
Report Series Relation

It may be seen that task analysis is essentially a tool for developing detailed functional descriptions of what man must or could do in implementing functions assigned to him. A task analysis usually carries along with it, of course, other information such as identification of the environment in which performance must be carried out and identification of the specific hardware to be employed. As a tool, it is quite appropriate that it be employed in a system development cycle whenever it is useful. If one considers the development cycle model employed in this series of reports, it appears that task analysis could be employed with profit as a tool to assist in the implementation of several activities in the development cycle. However, when it is used in different activities, it will, of course, be used to generate different data. For example, it may be used as a tool to develop the data necessary to support the recommended action for crew size. It may be used again as a tool to develop the data necessary to support the recommended personnel product solution to the maintenance problem. Again, it may be used to develop the detailed data necessary to design and fabricate training materials and job aids.

VIII. SYSTEM SYNTHESIS

Thus far in this report the concepts described have been concerned primarily with general descriptions or descriptive devices for the system or subsystems and/or analytic devices for analyzing a system or portion of a system into its component parts. System synthesis is concerned primarily with integrating the data developed during analysis procedures to form the basis for a more global understanding of the workings of the system as a whole.

The term synthesis itself may be viewed as having two connotations. The first is a definition of the term as an antonym to analysis, and refers to the process of starting with the highly specific components of a system and, by a process of combining and building, ultimately ending up with the top-level functional descriptions of the system. The second connotation of synthesis refers to the process of integration across system data in order to derive conclusions or descriptions of the system based on a unification of components. Distinction between these two concepts may be seen readily in the following hypothetical paradigm.



If one views the process of system analysis as appearing graphically as a triangle resting on its base, with general broad functional descriptions of the system at the top of the pyramid and specific descriptions and requirements at the base of the pyramid, then analysis may be seen as the process of going from the top of the pyramid to the bottom. Synthesis may be seen as the process of going from the bottom to the top. In this case, synthesis would be used in the first connotation of the term. If at any horizontal level of description all component data were combined to form some new analysis or understanding of the system, synthesis would be used in its second integrating meaning.

Four major topics are discussed in this chapter. They are system synthesis, contingency analysis, functions criticality, and simulation modeling. In these four topics, both connotations of the term synthesis are apparent. Of particular interest in this chapter is the discussion of simulation modeling. This term and the concepts related to it are of major interest in current system analysis as a means for providing the integration and global understanding of the system. The term is presented in this chapter not as a representation of a technique widely employed in the aerospace industry, but rather because of its broad potential impact in the synthesis of complex man-machine systems.

System Synthesis

Synthesis is the process of combining performance entities within a system to form a set. Functions analysis is the generally accepted process of partitioning the system into smaller units, however there is no generally accepted method of synthesizing elements.

In the course of preparing system documentation for the development of an operational system a number of essential aspects of that system require data produced from several analytic activities. These data must be synthesized across the system documentation for direct application to a given problem. Several examples demonstrate this point. In identifying and developing both operational and maintenance training procedures it is necessary to collect data from several analyses performed in system documentation. To determine requirements for simulation modeling or detailed end-item design requirements, synthesis of system documentation must be performed. This is not to say that a system cannot be analyzed in order to specifically obtain training simulation or design requirement data. However, such analyses would represent an enormous redundancy in effort as the information supporting those analyses would already have been collected for other purposes in the normal course of system development documentation.

Synthesis may be performed at virtually any level of system development. The above examples illustrate synthesis at levels of specificity which can be and frequently are quite detailed. Identifying reference system requirements, design conceptualizations, or verifying adequacy of the design represent system synthesis performed at a relatively high level of system abstraction (that is, at top levels of specificity).

As stated earlier, there exists no one technique for performing system synthesis. A major reason for this lack of technique is the fact that system synthesis, as may be seen in the above examples, is performed to accomplish a number of different purposes. The techniques used to perform the synthesis are therefore highly contingent on the specific purpose in mind. However, there are several general methods which are frequently employed as part of a system synthesis effort that warrant discussion, not so much as the tools of system synthesis but as broad methods employed during the synthesis effort. These methods are, as a rule, idiosyncratic to a particular purpose but may be discussed in a more general sense. Further discussion of these methods appears in subsequent sections of this report. Included are contingency analyses, determination of functions criticality, and simulation modeling.

While there is no one synthesis tool now used throughout the aerospace industry, it is possible to describe some of the characteristics of such a tool. Generally, the characteristics are included in the following. These characteristics are in addition to those implied by roles of synthesis in the above discussion.

True and apparent availability.—The tool must provide a means for measuring both true and apparent system availability under various conditions of operation. True availability represents the actual condition of the system despite its declared state, i.e., despite what it may appear to be. Apparent availability refers to the declared state and will not be compatible with true availability if the malfunction detection system is less than perfect. Measurement of true and apparent availability represents the minimum criterion measures the tool must have if the maintenance variables are to be related to the total system. An additional capability which would be highly useful would be to determine the probability of success of the various types of missions required of the system.

Flexibility. —The tool must be flexible to allow the operation of the system under various conditions of the maintenance and/or operational variables. In order to provide a means of relating these variables to the criterion measures, the variable must be controllable. The maximum extent of control is debatable. At a minimum, the tool must be capable of determining the effect of a significant change of the variable on the total system.

Intermediate criterion measures. —The tool must provide a means of measuring intermediate criterion measures such as maintenance turnaround time, maintenance man-hours per operating hours, fuel consumption, and resource utilization. These measures will be necessary to determine the relative cost of maintaining a given level of availability.

Relative importance of problems. —The total number of problems possible in the development of a complex man-machine system is so large as to be almost incomprehensible. Any variable and/or resource produces at least one potential source of problem. The personnel involved in the development of a system constantly face the problem of predicting the impact of the problems. Personnel time and money are limited, and expensive expenditures on problems of relative unimportance would not assist in an efficient development of the system.

The tool must provide a method of relating resources or variables to the system operation primarily in terms of their relative effect on criterion measures. The decision-makers can then consider problems within the context of the total system. This should not be construed to mean that the "relative contribution to the system" should be the sole criterion for judging the importance of problems. Numerous factors determine whether problems should be investigated. These include consideration of the system manager, the level of confidence one has to the extent to which the problem has been identified, acceptability by other customer groups or agencies, etc. However, one of the major considerations should be the relative effect of the potential problem on the system. If the tool can assist in determining this relative effect, it will aid considerably in increasing the effectiveness and efficiency of the development sequence.

Support trade-off studies. —Two major categories of trade-off-study parameters are measures of value and cost. Value, in this case, refers basically to its contribution to the overall system performance. If the tool provides a useful means for synthesis, it should also meet part of this objective by providing a measure of value in a method of relating variables and resources to system criterion measures. The tool should also provide some means of determining at least the utilization cost which can then serve as an input to the trade-off study.

The tool should also provide a means of determining whether trade-off studies are merited. If the tool can meet the objective of determining the relative importance of problems, it should also be able to meet this objective. Information on the basic characteristics of the system such as the input-output ratio may affect the variables on this ratio. The extent to which the variables interact in their effect on the system criteria, true distributions, etc. should be useful in determining whether trade-off studies are required, as well as conducting trade-off studies. It is important to recognize that this is not a tool for the total trade-off job. It simply provides the data which could be useful in conducting trade-offs and to verify the results, i. e., to support trade-off studies.

Support allocation of requirements and/or means. —To assure proper development of the system, it is necessary to provide quantitative criteria which can serve as design specifications. It is generally true that quantitative criteria for the personnel subsystem portion of various systems is practically nil. Realistic and valid requirements are needed both for the performance time and the allowable ranges of personnel performance errors. Without these parameters, a design of personnel performances and training tend to be oriented toward projected interpretation of what man can and/or should be able to perform. Total attention can be anticipated for the required reliability of human performance during either design or training.

Most of the resources in a system can be traded off against each other. Deficiencies in one type of resource frequently can be overcome by increasing, or changing, another type. For example, deficiencies in human performance, or lack of sufficient number of personnel, can be overcome to some extent by increasing the role of equipment. Similarly, low spare levels of end items can be maintained by increasing the capability to repair these end items.

The problem of allocation is not a simple one since it must consider the possible interactions between the numerous variables comprising the system, and the basic characteristics of the system in terms of its reaction to fluctuations of the inputs. The tool must support the allocation of resource levels, time and errors. It should be noted again that the objective of the tool is not to conduct the allocation, but rather to provide support data.

<u>Report Series Relation</u>

In the system development paradigm developed in these reports, systems synthesis, particularly in the sense of integrating system data, plays a very important role. Synthesis takes place (and may be seen as specified nodes in the development model) at the conclusion of major phases of the system development. Key points at which the synthesis is provided are:

1. Functional design of prime system;
2. Functional design of additive set;
3. Final means allocations and interface design;
4. Preparation of fabrication models; and
5. Fabrication of the system.

In addition to the major identified synthesis nodes, integration of data and products is identified in the model at all points at which data or products are assembled. In the symbolic development model, all logic symbols "AND" imply a synthesis or integration effort.

Contingency Analysis

Optimization of system design and personnel preparation programs depends to a considerable degree on the identification of a practical total performance continuum required of both equipment and personnel during system operations. The definition of this performance continuum requires awareness of standard events, procedures and tasks, and, in addition, probable events and occurrences to which personnel must respond during the course of system operation which are outside the realm of nominal performance. These non-nominal events are usually called contingencies. Identification of these events is the outgrowth of contingency analysis, frequently defined as ". . . that portion of function and task analysis performed to identify nonroutine situations with which a system may have to deal, so as to determine any special human performance required by these events: e.g., extreme environmental conditions, or enemy activities." (AFSCM 80-3.)

The purpose of contingency analysis is to provide procedures and means requirements enabling the personnel subsystem to cope with contingencies when they occur during the operation of the system. Three basic objectives are implicit in this purpose:

1. Development of information about potential contingenceis at a level of detail and specificity translatable into design requirements to be considered in design optimization of means to accomplish each function;

2. Derivation of man's role in the contingency situation after system design optimization, considering cost effectiveness and system effectiveness;

3. Translation of man's role in the contingency situations into skills and knowledge requirements and integration of these requirements into design specifications for man.

Contingency analyses may be seen as having broad ramifications to all other aspects of personnel subsystem data acquisition. Results of the analysis may demonstrate requirements for additional equipment, changes in man-machine interfaces, and changes in training requirements. Because the analysis depends heavily on functions and task analyses data to support its analytic efforts, it is typically performed subsequent to the other analyses. To allow for contingency analysis, frequently there is preliminary identification of potential contingencies made during the final stages of task analysis. This identification may be in the form of noting potential malfunctions or potential effects elicited by improper inputs to the task or improper performance of the task resulting in degraded outputs.

Central to the conduct of contingency analysis, is the definition of contingency itself. The definition is based on the assumption that nominal tasks developed during functions and tasks analysis represent the best possible choice of man-machine interactions and definition of man's activities during the operation of the system. Contingencies may be defined as an event or occurrence which results in a system state eliciting: implementation of other than nominal activities on the part of the personnel, either temporarily or on a permanent basis; or deletion of any portion of nominal activities involved in the operation of the system.

Two major conceptual products result from the contingency analysis. The first is identification of potential contingencies which can give rise to another than nominal response. These contingencies may, on the basis of the analysis, be demonstrated to have various effects on the overall effectiveness of the system. In the case where the probability of contingency occurrence is high and the effect on the system outputs is also high, changes or modifications in system design may be required to obviate the problems posed by that contingency. The second product is identification of the procedures required by operational and maintenance personnel in order to respond to the contingency in a way least degrading to system effectiveness. Since all major aspects of contingency analysis must be related to the system as a whole and, more precisely, system effectiveness measures, these measures must be very precisely stated during the initial formulation and developmental analysis of the system.

Contingency analysis may serve as a very useful tool in the development of a system for purposes of integrating the diverse data produced by systems analysis. It is also extremely important as a device for uncovering the limitations and inadequacies of both equipment and man's capabilities within the system. In the latter capacity, it may be used as an evaluation tool to identify conditions present in an operational system that would result in severe degradation of system performance. Identification and isolation of those factors which can cause severe degradation of system performance can, if identified in the earlier stages of development, be modified so that contingency procedures would not be necessary. That is, if a particular component in a system has a relatively high probability of failure, and if the effect of failure of that component on the remainder of the system is a severe reduction of system effectiveness, then measures can be taken in the development of the system to increase the reliability and/or point availability of that component—by duplexing it, by redesigning it, or by changing allocation of system functions.

Report Series Relation

Contingency analysis is not a term requiring special consideration in this sequence of reports. In talking about the system development cycle model, the term can properly be used in the manner described above. Contingency analysis must be used in conjunction with reliability analysis to determine comprehensive requirements for each active loop, and thus for the total additive set. The initial analysis which establishes the need for an additive loop does not, however, include contingency analysis, but is based upon a comparison of the target probability allocated to a function together with the reliability of the means by which the function is to be implemented.

Functions Criticality

Functions criticality refers to the effect of any function on the total system effectiveness. That is, determination may be made of a function's sensitivity (in terms of output) to changes in input and constraints, on both follow-on functions and total system effectiveness. This type of examination is frequently performed at lower levels of function specification. This is because in initial top-level and first-level functions descriptions, all functions may be said to be critical to the completion of the mission. It is only in lower levels examinations that functions may be distinguished in terms of their criticality. Criteria usually applied in assessing the criticality of a function include the following:

1. Will the loss of the function abort the mission?

2. Will the loss of the function increase the time, effort, and money cost of the mission?

3. Will the loss of the function degrade the reliability of the mission?

4. What is the relationship between degradation of function input and functional output degradation?

On the basis of examining each function in terms of the above or similar criteria, the criticality of each function may be assessed. If it is found that the function is in fact critical, the function may be further examined to determine the probability of occurrence of degradation. If the probability is high, then steps may be taken to augment the functional capability by providing alternate functions or changing the nature of functions allocation to increase reliability, or redesigning equipment to minimize either the potential degradation of the function or the relation between the graded input and the graded output. If, on the basis of the examination, the function is not found to be critical with respect to the identified criteria, then it may be possible to design the system so as to eliminate these functions. That is, if a function is found to be not critical, i.e., not related directly to system effectiveness, then some question may be raised as to the necessity of performing that particular function.

Examination of functions criticality is usually a part of, or a parallel effort to, the analysis of contingencies. It requires as baseline information the functions reliability and system-effectiveness measures. Appropriate levels for examination would best be centered around those levels in the functional derivation that are immediately adjacent to identification of man-machine allocations. A major output of examining functions criticality is the information it provides about the design adequacy of the function. This is most clearly seen at those levels in the functions analysis where means are identified.

Report Series Relation

The process of determining the criticality of each function in a system description is important when the description is one which does not connote the relationship of each component function to overall system probability of success. Many of the block-diagramming techniques in common use do not preserve this information and do not permit translation to a system description in terms of probability statements. When a system calculus such as that described in Report IB is employed, the process of determining functions criticality reduces in concept to the translation of a function description of the system into an analogous probability statement. With the help of a computer, a description of the system in terms of probabilities of functions may be explored at will to determine the effect of any hypothesized change in reliability.

Simulation Modeling (Computerized)

Simulation models in general have had a long history of application to systems analysis problems in the development of complex systems. They exist in a variety of forms, from highly detailed physical models of, say, river-flow or wind-tunnel modeling, to electronic analogue computers, and, finally, the complex symbolic digital-computer models. A characteristic shared by all these forms of simulation models is that they permit a simulation of various component system factors to be exercised as a whole, thus permitting a variety of factor values to be traded off without the time and cost necessary for trade-off studies using the completed system or system component. Of course, an assumption underlying the use of simulation models is that the results obtained from exercising the model may be used to predict performance of the system.

Inasmuch as a simulation model, regardless of its form, permits the study of complex factor interactions, it can be an extremely useful tool in the development of personnel factors in system development. It is also an extremely powerful tool for providing system synthesis activities.

While there are several forms this type of model may have, the one growing in use today is a computerized stochastic simulation model in which the actual system is both logically and digitally simulated. The model is generally controlled by basic inputs such as mission demands and mission phases. The profile of such phases is deterministic in that it is preestablished and fitted to a digital computer. The stochastic nature of the model arises from allowing failures to occur in a "random" manner whenever the system or its various components are in operation. Functions in the model are characterized logically, the specific manner of characterization depending on the function being simulated. Therefore, the basic unit of performance for simulation must be compatible with the basic unit for the actual system. Functions have been selected as the basic unit of performance for many of the more recent models.

The basic functional element of the simulation program is a logical function which is used to describe any of the functions depicted in the functional flow diagram. This function is characterized by a set of possible input states, data vectors describing the function, and a set of output states. The functional input states are determined by preceding functions. The detail specification of input-state conditions depend on the level of simulation of all pertinent functions. The function data vector describes the functional activity itself, in terms of such factors as performance time, error and damage probabilities, and specifies the resource requirements for the function.

A model is controlled by basic inputs which will vary depending on the nature of the system being simulated. The output of the model is a set of statistics gathered through simulation. There are a number of areas within the development of the system to which a simulation model may be appropriately applied to provide system synthesis data. Several of these are mentioned below.

Personnel requirements analysis. —The personnel requirements analysis takes place after allocations have been made on individual functions. Subsequently, it is necessary to determine the specific performance required of personnel, capabilities required for such performances, and the total quantity of personnel required for each type of capability. The major portion of this process is design or a means-allocation type of task.

A model can be used to help determine the relative importance of the various functions in a system to the overall system performance. The indicated relationship between functions and the overall system performance can then be used to determine "criticality" of the personnel role in a given function, which in turn can be used to establish priorities for detailed examinations. Such information could be used to establish priorities for task analyses. Task analyses conducted for every function in the system can result in a large amount of data, a major portion of which may not be useful. Information on the relation between individual functions to overall system performance may be used to determine whether detailed examination of the function for personnel performance is merited. Areas in which a model may provide support include:

1. Indicating the frequency of usage or per cent utilization for each type of personnel;

2. Determining the total number of personnel of each type required to maintain a given level of availability and flexibility of the maintenance subsystem; and

3. Evaluating any level of personnel types and number in terms of adequacy to meet the availability requirements and/or the contribution to maintenance turnaround time.

Another manner in which the model can be useful is in providing an initial estimate of both reliability and performance time required of the personnel. Ranges of allowable errors and times can be studied using the most pessimistic, optimistic, and most likely estimates for personnel performances. The lack of any significant difference in system performance using the optimistic and pessimistic estimates would indicate the range within which personnel performance can be conducted and provide a greater tolerance for training. If there is a significant difference, areas in which further examination should be conducted by training will have been identified.

The model may also be used to determine the relative advantages of different manning concepts. For example, a concept of maximizing the level of personnel and sharing such personnel across subsystems can be compared against a concept of using the smaller number of highly-skilled personnel assigned to each subsystem. The capability to interchange personnel may be an important factor in reducing the cost of the system. If personnel are allocated separately to each subsystem, the total number of idle hours can become quite extensive. Conversely, interchanging personnel between subsystems can reduce the total idle time since part of the idle time for one system can be used in another subsystem. However, the degree to which the personnel can be interchanged will depend on the differences in capability (consequently, training) required by the subsystems. The model can be useful in determining the relative savings realized by interchanging between various combinations of subsystems. Trade-offs can then be made by adding training costs data.

A model can also be used to study the utilization of personnel of different levels for a given function depending on difficulties encountered during that function. This is an extremely critical use of a model, since one of the major difficulties encountered by the services is the allocation of high-skill technicians to functions which do not always require high skills. Using high-skill technicians to perform low-skill jobs is not only wasteful, but frequently results in significant degradation of morale and, consequently, performance. Furthermore, the lack of usage of high-skill capabilities also results in degradation of the high skills for which the personnel were originally assigned. The model can be useful in determining the percentage of high-skill personnel required if the analysts provide a criterion for determining when high-skill personnel are required during the performance of a given function. Furthermore, a model can provide the relation between personnel performance, time expressed in terms of error, time and number of personnel utilized per unit of time; system parameters such as availability and maintenance turnaround time, and other system variables such as spares utilization, test equipment utilization, etc.

Human engineering. —A model can support human engineering by assisting in the determination of the relative importance of functions, allowable ranges of error and time for personnel performances, and the frequency with which any given function is required. These will indicate the extent to which man will interface with his surrounding equipment environment, and the importance of this interface to overall system performance. The quantitative criteria for performance time and error should be useful for examining the interfaces. If performance time and/or allowable error must be low, greater emphasis should be placed on human engineering with the interface. On the other hand, if the allowable range of error and time are fairly wide and the frequency of occurrence is fairly low, extensive human engineering would not be warranted. This does not mean that general human engineering principles should not be applied, but special studies of the man-machine interfaces probably would not be justified.

The model can be of further assistance if quantitative estimates are available on the extent to which the man-machine interface affects performance time and/or error. By exercising the model, the effect of performance degradation on overall system performance can be determined and expressed in terms meaningful to system designers, such as the effect on availability, maintenance man-hours per operating hour, etc. Human engineering efforts can then be concentrated on those areas having the greatest potential for system degradation.

The relative effectiveness of two man-machine interface considerations can be studied adequately with the model if the differences can be expressed in terms of performance and/or error. In most cases, however, the human engineer (or maintainability analyst) will not have relevant data available. Therefore, it will be necessary to study the problem specifically for the system. It is not necessary to have the actual equipment available for the studies, but time and some mock-up must be provided for such studies if useful tradeoffs are to be conducted.

An inherent danger in initiating a human engineering/maintainability laboratory is that the laboratory may be designed to be much more sophisticated than is required by the system problems. The model can be highly useful in overcoming this potential problem since it can provide an indication of the relative importance of various functions, and, consequently, problems within the functions. The laboratory can then be designed to study problems which will have a significant effect either on the performance or the cost of the system.

Training. —Quantative criteria, such as reliability, for personnel performance will not be useful unless training can respond to these criteria. Early identification of allowable errors and time should be useful to the training personnel to determine whether in fact they can respond to the criteria. This is not a simple matter since the state of the art in training is not sufficiently advanced to allow prediction of personnel reliability. However, it should be useful in training standards and developing proficiency tests which can be used in the course of training to determine whether the criteria can be met. Furthermore, areas in which training should be emphasized can be readily identified by the relationship of the individual functions to overall system performance indicated.

If a range of allowable errors and time can be established, training personnel can examine the training implications for the most optimistic, the most pessimistic, and most likely estimates of time and errors. If the training analysts can identify different training implications, it should be possible to incorporate training implications in system trade-off studies. If training analysts cannot identify different training implications, it is quite possible that training research requirements will be identified; i.e., what research is needed to allow training to respond to reliability requirements.

Techniques for treating training in a quantative manner are quite scarce when compared with reliability techniques and equipment design. However, some relatively valid techniques are available and should be utilized. Primary emphasis should be placed on the validity of training tests and the placement of such tests throughout the training program. The question of whether a given training course will meet the reliability requirements can be approached by considering the information transfer process.

Personnel planning information (PPI). —Studies with the model will provide useful data for inclusion in the PPI. As indicated earlier, the studies can provide allowable ranges for time and errors which will be useful in conducting more detailed trade-off studies during the system design and prototype substages. Trade-off data can also include the relative effect of errors in given functions to overall system performance, and the relation of these errors to cost elements, such as support equipment and spares utilization.

Among the more useful inputs the model can provide for personnel planning are the potential ranges of quantity and types of personnel. The range should be based on anticipated errors and prediction for system variables which would have a bearing on the quantity and quality of personnel, e.g., mission demand and reliability estimates. Estimates of both tend to be highly unstable during the early stages of system development. The model can indicate the anticipated increase in the number of personnel required with changes of reliability, e.g., for 25% reduction reliability with no change of mission demand, 25% reduction of reliability and 25% increase of mission demand, etc.

A model can also provide other information which will be useful for personnel planning such as anticipated frequency of various functions, peak manpower demand situations and other changes of interfacing elements which could affect personnel planning.

System design. —A model can be used not only to evaluate the adequacy of inputs from the contractors, but also to check the compatibility of their estimates. Contractors may develop systems in a nonintegrated manner unless valid feedback is received from the service monitors. This is particularly true for personnel elements, since personnel elements are frequently developed in an off-line function.

A major problem facing many groups responsible for developing personnel elements in industrial firms is the inability to obtain the relevant system information from their fellow system developers. It is not uncommon that personnel elements will be based on one set of estimates, spares will be based on a different set of estimates, and ground support equipment will be based on a still different set of estimates. There have been cases where all three were incompatible with reliability estimates submitted officially by the contractor. The incompatibility frequently continues to exist until the system is actually put to use. A model can be extremely useful in detecting such incompatibilities if the officially submitted data are used as inputs for the model.

A series of model runs can be scheduled each time officially submitted data are scheduled. Special studies can be conducted in accordance with problems detected during the scheduled runs. The relevant information should be related to the delinquent contractors.

Subsystem test and evaluation. —A major contribution of a simulation model is its usefulness as a tool to evaluate total maintenance or the personnel subsystem before the actual subsystem is made available. In a sense a model enables continual evaluation of the subsystem throughout its development history, from its conceptual stage through the various stages of definition, and during field evaluation.

Subsystem evaluations with the model may continue throughout the field evaluation program. It is anticipated that unpredictable problems usually arise during the field evaluation program. The model can be used to determine the effect of the problems on the system. In certain cases, it is not possible to measure all of the variables in the field and the model can be used to determine the variations. The model is also useful for determining the causes of problems noted in the field.

Report Series Relation

Simulation modeling is an important tool in the development of a system. It is applicable to the concepts defined and developed in this report series.

IX. HUMAN ENGINEERING—MAINTAINABILITY

When the system has been specified to its basic components, and concurrent with the development of man-machine allocations, concepts relating to human engineering and maintainability are applied. These two terms reflect, to a degree, the old and the new in system development work. Human engineering as a term and as a technology, has been applied to system and subsystem development for a relatively long period of time. One may trace its origins at least to the early work of Taylor and Gilbreth at the turn of the century in their concern with early man-machine relations. Historically, human engineering probably came of age during World War II and man's first intimate interaction with complex equipment. It may be seen, therefore, to be one of the oldest disciplines in system analysis.

Maintainability, on the other hand, represents a relatively new concern of the system analyst. In many respects, its growth parallels the engineering development of concepts related to equipment reliability and maintainability. Since both terms are concerned generally with the human's performance with complex equipment, there may be no need to distinguish them as separate areas of concern even though they are usually concerned with the separate areas of operation and maintenance. Since in current aerospace industry practice, however, distinctions are drawn between the operation and maintenance of a system, human engineering and maintainability are presented as separate topics here.

This chapter includes discussion of four major topics; human engineering, maintainability, human malfunctions, and human reliability. That these topics are presented as distinct concept areas does not necessarily imply that in system development they need be treated independently. In actual practice, the individual scientists responsible for one area are frequently the most competent to analyze and integrate the others.

Human Engineering

Human engineering is a term which has been employed by the aerospace community for a number of years. In a broad sense its meaning is understood by virtually every practitioner within this community. However, to avoid possible confusion the term is used here to mean "... the determination of man's capabilities and limitations as they relate to the operation, maintenance, and control of ... systems, and the application of this knowledge to the planning, design, and testing of each system to ensure efficient, reliable, and safe human performance." (AFSCM 80-3, ref. 3, p. B-1-1). As such, human engineering is only one part of the personnel subsystems study. The latter includes, besides human engineering, life support, personnel selection and training, training equipment, job performance aids, and performance measurement and evaluation. The purpose of applying human engineering principles to system development is to enhance new systems by designing them to exploit optimum human capabilities without risking degradation of system performance by imposing limitations on the human operator or maintainer as a result of improper design of equipment. In general, within the context of development systems, human engineering is the application of psychophysical research to the design requirements and constraints of the system in question. The areas involved are, as a rule:

1. Sensory and perceptual capabilities;
2. Motor skills;
3. Information handling and decision making;
4. Group communications;
5. Body dimensions, reach and workspace requirements;
6. Environmental performance capacity.

During the system analysis process, human engineering principles and procedures are applied in order to determine man-equipment requirements for system operation maintenance and control functions. These data are essential for the appropriate allocation to the system function. Similarly, these data are used to determine performance requirements of man and equipment interfaces as well as equipment and personnel performance criteria. Human engineering data serve as rationale for allocating system functions. In addition, human engineering data are used to identify specific pieces of equipment to be used by the system determining the equipment-oriented tasks that should be performed, the design of both major and minor system components, and in determining the performance measures to be applied throughout system design and development in order to check on adequacy of function allocation equipment, etc.

Human engineering data, as previously mentioned, are the result of applied research in various psychophysiological areas. These results are frequently stated in terms of statistical analyses. Consequently, research results require interpretation before they can be applied to the design of any particular system. That is, knowing the mean height of astronauts would not permit one to design hatch sizes because the hatch would be designed for the majority of (if not all) astronauts who potentially may use that hatch, rather than the average astronaut. In many cases in aerospace system development, potential users of the equipment make up a very small nonstandard sample of the general population. Thus, it is sometimes misleading to use experimental data obtained from sampling the general population. During the Mercury spaceflights it was not necessary to have knowledge of population parameters with respect to astronaut height, weight, agility, visual acuity, etc. —the capsule is not designed for use by the average population, but rather for use by a very select group of individuals who themselves could be measured on these parameters. Thus, equipment could be designed for the specific requirements of the user population rather than statistical averages.

Similarly, it is obvious that the nature of transfer of experimental results from earth environment to zero-gravity space environment is as yet largely unknown. The result of these limitations to application of human engineering data base has been to enhance and increase the role of the human engineer during the development cycle of space systems to include the conduct of system-specific human engineering data collection. Thus, for example, visual acuity criteria applied to space programs is frequently determined by experimentation conducted during the course of the development cycle for that particular system.

Report Series Relation

As used in these reports, the term human engineering refers to a technique for solving the problems associated with man-machine and man-man interfaces.

Specifically, human engineering is a technique for ensuring that there is no degradation in system reliability which can be attributed to failure of passage of information, materials or energy across man-man and man-machine interfaces. Human engineering is employed to ensure reliability across both operator performance interfaces and maintenance technician performance interfaces. At each individual interface, the process of human engineering may result in:

1. Requirements for training man so that passage across the interface in question will be reliable or optimal; or

2. Design of equipment at the interface such that the signal presented to man or by man will cross the interface with reliability and validity.

Workspace design is concerned with the consideration of two or more interfaces at once. Thus, in practice, workspace design is concerned with the design of all interfaces such that taken together there are no degrading interactions among them. Activities focused upon the problem of assuring the reliable passage of information and material across man-machine interfaces are specifically called out in the development cycle model.

Maintainability

Maintainability is a term used more and more in personnel subsystem development. It may be traced to the development work incorporating reliability in estimation of system performance. Generally speaking, it refers to the degree to which a system, subsystem, or component can be maintained by personnel assigned to that task. It has to do more with the repairability of system components and the manner, techniques and philosophy behind such repairability than it does reliability, i.e., the degree to which a component will continue to function at some specified level of performance over a specified period of time. For the personnel subsystem analyst, reliability focuses on two major concepts: mean time to restore (MTTR) and mean time between failure (MTBF). Implied by, or a part of, these concepts are the notions of probability of successful performance and point availability. While these notions are necessary in the formulation of appropriate design concepts and maintainability concepts, they are not essential to the discussion of an analysis of maintainability, particularly within the context of personnel subsystems. It is of course true that the amount of time required to repair or restore a portion of a system to operational capability, or the frequency with which that portion of the system requires such repair, is of great interest and makes substantial impact on various aspects of system manning concepts. However, the ramifications of reliability to the personnel subsystem may be disassociated from many of the key concepts involved in maintainability. That is, it is possible and fruitful to distinguish the interactions of maintainability and reliability to personnel subsystem development from the major effects of—or primary concepts central to—each of these principal terms.

Maintainability may be seen to include at least three major areas of concern. The first is providing means for identifying personnel maintenance tasks. That is, a functional model of a system may be overlaid with the development of maintenance functions. As the system operational model can be made more and more specific through functions analysis to include finally the requirements necessary to make means decisions, so can the maintenance functions. Obviously such allocations cannot be made until the requirements, constraints, and design philosophy toward maintainability have been clarified and analyzed as part of the functions analysis process. All considerations of man's capabilities, environmental constraints, human engineering standards and procedures must be incorporated into the allocation process. The process for deriving human maintenance tasks is essentially the same for operator tasks.

While man, as an operating component of a system, may perform in many capacities varied in both kind and nature, it is possible to reduce the types of tasks performed by a human in order to maintain a system to several specific categories. A number of different terms have been applied to express the categories of maintenance tasks. In general they are as follows:

1. Detect need—Determine the need for, or evidence of, a malfunction within a component subsystem or system.

2. Troubleshoot—Determine the specific malfunction eliciting the degradation of performance observed in (1) above.

3. <u>Reinstate system performance</u>—Alleviate the malfunction or performance degrading character of the equipment and reinstate to previous system acceptable levels.

4. <u>Checkout</u>—Subsequent to performing remedial action, determine whether the action taken was successful and did in fact reinstate adequate system performance.

The application of these categories to unscheduled maintenance events is obvious. However they may be equally applicable to scheduled maintenance. In this latter case, detection of a maintenance event is performed by predetermined schedules of maintenance activities. Troubleshooting is a function of the description of the scheduled event to take place, and identification of the part component subsystem, etc. to which such scheduled maintenance is to be directed. Reinstatement of system function and checkout are directly applicable to both scheduled and unscheduled maintenance events.

The second aspect of maintainability warranting discussion is that of design for maintainability. This refers to the application of maintenance design concepts to the man-machine interface in order to facilitate the maintainability by the human on the equipment in question. Examples of design for maintainability may be found in the provision and design of access doors and hatches to engines or otherwise inaccessible components, provision of special tools to reach inaccessible parts, determination of which equipment will receive the greatest amount of maintenance, scheduled or unscheduled, and location of these for rapid and easy access of the human maintainer, etc. If a component, part, or subsystem is to be maintained primarily through scheduled maintenance, then the dictates of this concept are that it be positioned in such a way that the scheduled maintenance events can take place quickly and with a minimum of equipment downtime. In many instances, application of this concept can require major redesign of specific components parts, such as lubrication stations. Standardization of maintenance required tools also reflects design for maintainability. Criteria frequently applied to the design of man-machine interfaces for maintainability include the following:

1. Ready accessibility.
2. Ease of part maintenance.
3. Safety to both the equipment and the maintainer.
4. Number and weight of required tools.
5. Clarity of work required.

The above list is neither complete nor exhaustive, but rather representative of the kinds of criteria applied to design for maintainability. Concern for the application of these criteria to maintainability design is frequently not a clear-cut proposition—in many cases, during the actual design of equipment, many or several of the appropriate criteria are, at least on the surface, incompatible. This requires criteria weighting and trade-off studies in order to assess the best or most useful design concepts to be employed. When possible, these trade-off studies are made within the context of system-effectiveness and/or cost-effectiveness models. Obviously, in the design of equipment for maintainability, consideration must also be given to subsystem reliabilities and criticality (as defined by system-effectiveness models).

A third aspect of maintainability is the reduction of operator-caused malfunctions. In the previous two areas discussion has focused on identification of the tasks required to perform maintenance and the nature of the maintenance man-machine interface. In this case, however, the concern is with the operator, not the maintainer. There are many cases of equipment malfunctions traceable to improper performance on the part of the equipment operator. It is a function of analysis of maintainability within the personnel subsystem analysis to determine the means of maintaining operator skills and performance, and his performance with respect to the man-machine relationship at levels required by the system.

There are several areas of system development in which operator malfunctions may be reduced. One such area is in the original man-machine allocation. Full consideration must be given with respect to man's capabilities in general and specific kinds of people likely to perform the man-machine tasks, to ensure appropriate allocation of jobs and tasks to the human operator. A second area is that of equipment design. The design of the equipment to be used by the human operator must facilitate the operator's performance as well as maintain his level of performance to those standards required by the system. Poor equipment design may ultimately result in a human-induced malfunction as a result of fatigue, or other operator errors, caused by the location of switches, dials, etc. in inappropriate positions. The nature, design, and content of job aids identified with each man-machine allocation, and subsequent task identification, may make a critical contribution to the frequency and magnitude of operator-caused malfunctions.

Another area that may be mentioned here concerns the general concept of manning. Determination of how many operators, at what level of skill and knowledge these operators should be, and what the relief schedules for these operators should be, can be used to reduce operator-caused malfunctions. The operator's performance on a given task is determined by his skill level, training, motivation, the design of equipment with which he is dealing, and the general ambient environment. It is also in part determined by the whole panoply of psychological factors making up his personality. The interaction of these factors and the manner in which they contribute to operator reliability is, of course, quite complex and to a large degree unknown and certainly unquantified at this time. There are, however, several human error models that attempt to derive human reliability figures either based on certain assumptions made about a set of factors contributing to human malfunction, or which incorporate, in the model, various causal agents as variables. It is beyond the scope of this report to critically review the human error models thus far produced by the aerospace industry. To a large degree, these models, while having a great deal in common, are idiosyncratic to specific applications. Generally, these models may be distinguished into two groups. One group incorporates effects of fatigue and/or stress as contributing agents to the degradation of human performance; the second group assumes a random distribution of human error and treats the probability of error attributable to the human operator as a stochastic function. Thus far in the published literature there is little support for the validity of any current models as general models of human error.

The final area of concern to the development of maintainability concepts is that of the nature of maintenance to be applied. One may distinguish between scheduled and unscheduled maintenance events. Essentially this is the distinction between whether a system should be maintained by preventive maintenance activities or should be permitted to break down before maintenance is applied. In the course of normal system design, this distinction is not applied as a dichotomous concept. Rather, there are certain aspects of the system and system equipment to which one maintenance concept would be applied, and other types of equipment to which the other concept may be applied. Determining the application for either concept is contingent on system effectiveness and cost effectiveness for each as well as the intrinsic reliability of the system in question. Since consideration of equipment reliability has a major impact on the choice of maintainability concepts, it should be obvious that these concepts present not a dichotomy, but rather a trichotomous situation. That is, an alternative to either maintenance concept would be to design the equipment such that its reliability was so high as to require no maintenance of any kind, or to provide a duplex system such that when one component fails, the system is maintained by a second identical component with no loss in system performance.

Independent of whether the maintenance concept is for scheduled or unscheduled maintenance, the nature of maintenance provided also represents a choice point for the system designer. This is particularly true for the maintenance function of restoration. Restoration may be viewed as a continuum with complete part replacement on one end of the continuum and on-the-spot repair at the other pole. Between these poles are maintenance options such as partial replacement, repair in maintenance shop rather than on-the-spot, and substitution of minor equipment parts. The embodiment of the replace concept may be found in the growing trend in aerospace systems to utilize completely modular equipment. In its most simplified form such a concept may be seen in the design of the latest generation of solid-state computers. If a component within a module fails, a warning light goes on indicating which module is malfunctioning. The maintenance activity to restore system performance is to pull out the malfunctioning module and replace it by an off-the-shelf operating module. While such a concept has obvious advantages for the maintainer of the system in reducing the potential maintainer-induced malfunctions (resulting from improper restoration of the malfunctioning part), it does, however, have some obvious disadvantages. Among these disadvantages might be mentioned the almost overwhelming weight and cost penalties paid to provide storage for substantial numbers of spare parts for space systems.

The above concepts are of key concern in the development of aerospace systems. Hence they have been discussed at length in other reports in this series. In the course of their discussion critical concepts as well as exemplary techniques have been provided. To avoid redundancy, techniques are not discussed here.

Report Series Relation

Design for and implementation of maintainability is costly of resources. When the maintainability of the system being developed is set up as a separate criterion, it competes with other "goodness" criteria for the resources available to carry out system development. It can be seen then that unless there is an overall measure of system goodness which includes maintainability considerations, it will be difficult to determine where the greatest payoff lies in allocating development resources.

In this series of reports, it has not been necessary to employ the concept of maintainability as a system criterion. Provision for maintainability falls out quite naturally in the system development model as an action necessary to achieve the required reliability of additive loops involving maintenance technician performance. The model specifies that additive loops are designed into an operational system for a single purpose—to meet overall system probability of success goals. This being the case, there is a target increment of probability to be added in by each additive loop. It is then appropriate to use any and all techniques which might be available to the designer in order to design each additive loop so that it will achieve its target increment.

Human Malfunctions

According to some studies, sixty percent of system failures may be attributed to specific human errors of commission or omission. The factors underlying human malfunctions may be broadly distinguished in two principal categories. The first are the so-called psychological factors of fatigue, motivation, inattention, and stress. While a great deal of study has gone into these particular factors, there is so far a paucity of data that may be applied directly in the allocation and design of the personnel subsystem.

The second area of human malfunction factors includes the nature of equipment, the nature of man-machine allocations, training, performance aids, and task loading. Malfunctions attributable to the action of these factors may be seen to reflect an inadequacy or insufficiency of analysis during design allocation and requirements identification of the personnel subsystem. Careful allocation of functions to the human operator, conscientious design of man-machine interfaces, and properly developed training programs, technical orders, and job performance aids during the early development of the system can substantially reduce, or entirely obviate, most of the malfunctions associated with the human.

Report Series Relation

It must be recognized that an out-of-tolerance output of a human-implemented function will affect overall system performance to the extent dictated by the relationship of the function to the system as a whole. The overall effect will not reflect whether the failure was a human failure or a hardware failure. In short, human failures can and do have the same effect upon overall system output as do hardware failures. In view of this fact, provision must be made in a system development cycle to ensure not only that the personnel in the system are endowed with the capability to respond as required, but also that they will implement each assigned function with the required reliability.

The system development cycle model includes two principal classes of activities focused upon assuring that the anticipated reliability of human performance will be realized in the operational situation. Thus, there is provision for activities to develop a "maintenance subsystem" that will provide additive support to operator and maintenance technician performance. There is also provision for development of the Human Support Systems and the Safety Support Systems. The purpose of these systems is to sustain environmental conditions so that the reliability with which man performs each of his assigned functions will not be degraded.

Human Reliability

For all practical purposes, human reliability and human malfunctions (previously discussed) are two sides of the same coin. A major portion of the human malfunction discussion may be appropriately cited in this section. Very little information is available on the reliability of the human performing basic tasks. As the systems within which the human operates become more and more sophisticated, and the equipment with which he interfaces also becomes more sophisticated and idiosyncratic to the system, there is an increasing need for determining basic component human behavior reliabilities. These data are not currently available in the literature.

There are, generally, three methods of obtaining human reliability data. The first requires the reduction of human behavior to a standard set of activities analogous in intent to the industrial engineering concept of basic time-motion data. While such basic data stores have been initiated, as yet they are not at a stage of development to permit wide application to the design and allocation of current personnel subsystems. The second technique that may be employed is that of collecting human reliability data from current operational systems and employing them when the acts are approximately analogous to the tasks and procedures specified in a developing system. The degree to which the kinds of people in the new system are not similar to those utilized in the operational system, and the uniqueness of activities involved is the degree to which such data would be nonapplicable or misleading. A third technique that may be employed to obtain human reliability data is to study human performance in a simulation of the system in question. The nature and ambient environment of the simulation contribute markedly to the significance of reliability of data obtained in this fashion. One further disadvantage is that appropriate system simulators cannot be developed until the system itself has been designed to a fairly specific level. Thus, indications of low human reliability with respect to a particular set or sets of man-machine interactions may reveal limitations in the system design too late for these limitations to be ameliorated by redesign of the system.

Report Series Relation

The straightforward implication of the term human reliability is that there is a single number which can be used to describe the reliability with which a given man will perform. The immediate question to be asked is—"perform what?" The answer usually reveals that man will be called upon to perform many things, and that it is not necessary or possible to expect him to perform each of the functions assigned to him with the same reliability. It is therefore clear that it may be confusing to talk about human reliability; it may be much more useful to talk about the reliability with which man performs each separate function that is assigned to him. In this series of reports reference is made only to the reliability with which a specific function is carried out. The term human reliability is not employed because of its misleading implications.

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X. PERSONNEL SELECTION AND TRAINING

After the system has been analyzed in sufficient detail to provide identification of the tasks and task-associated equipment for both operational and maintenance activities, determination is usually made of the kinds of people to be selected and the training that must be provided for them. Generally this is done by identifying the skills and knowledge required by the tasks and overlaying them with the descriptions of the personnel population from which system personnel may be drawn. The adequacy of such a method is obviously contingent on the degree of comprehensiveness and specificity provided in the identification of required skills and knowledge. When individuals can be found with requisite skills and knowledge for the system, selection of personnel is said to have been completed. When the system being developed presents unique requirements in terms of skill and knowledge, only prerequisite background can be selected for in the choice of individuals to man the system. The difference between the level of training, knowledge and skills of the selected individual and the needs of the system are those areas in which training must be performed.

It may be seen that there are two critical choice points in the provision of adequate manning to the system. The first is in the initial characterization of skill and knowledge requirements for the system. Hand in hand with this specification must be complete documentation of skills and knowledge presented by the potential personnel population. That is, the skills and knowledge identified during the system development must be comparable, in terms of parameters and parameter measures, with available descriptive measures on the potential user population. When the two are compatible; the process of selecting from the population is to a large degree mechanical. The second critical area is that of providing the necessary training and training equipment for the selected individuals in order to bring them up to the level of proficiency and understanding necessary for required tasks.

Three major topics are discussed in this chapter: training concepts and plans, training equipment planning information, and skills. Knowledge—as a term applicable to this chapter's topics—was excluded from specification and discussion primarily because its meaning in aerospace industry usage is not at all private or idiosyncratic. Its use in this context is by and large the public meaning of the term.

Training Concepts and Plans

Historically, man devised mechanisms and then learned to use the mechanisms after they had been constructed. At best, training was a trial-and-error process. This training concept is no longer appropriate to the more complex systems of today. The nature of training individuals on the use of the mechanisms, and the development of skills and knowledge to support operation and maintenance of the system, must now be considered during the early development stage. Development of the concepts for training, as a rule, go hand-in-hand with the determination of tasks and task requirements for all aspects of the system. The coordination of training concept development and human performance identification may be seen in the sequences of analyses required to determine training plans. A representative sequence is as follows:

1. Determine what the human will be required to do as a component of the system—that is, what will the tasks and procedures be for both operation and maintenance activities.

2. Identify skills and knowledge required to perform these tasks.

3. Determine the job classification—that is, the kind of individual to perform each position within the system.

4. On the basis of descriptions of capabilities associated with each job category thus identified, and the skills and knowledge requirements of the tasks associated with that category, determine the additional skill and knowledge requirements for the job.

5. Based on the additional skills and knowledge required, determine the techniques, tools and programs necessary to provide the system with trained personnel.

Skills and knowledge required by the system for each individual are identified by requirements allocation and subsequent task analysis. Training objectives which include specific skills, knowledge, or attitudes, is synthesized not only from the requirements allocation and task analysis but also from QQPRI. These objectives frequently include such categories as:

1. Identifying,
2. Knowing principles and relationships,
3. Following procedures,
4. Making decisions or choosing courses of action,
5. Performing skilled perceptual motor acts, and
6. Maintaining desirable motives and attitudes.

Two major products result from analysis of training requirements. The first is a detailed plan for the kinds of training to be provided each individual and group of individuals within this system. This plan is concerned with allocating training responsibilities among categories of training such as whole vs. part-task training, system training, procedural training, etc. Having made the decisions necessary to allocate particular training requirements to various kinds of training, the second product is the requirement statements and ultimate design of specific training equipment to be used. This training equipment may take several forms—among them (in terms generally used in industry) are:

1. Trainers—a device or equipment which is used as a primary means of teaching personnel to perform a particular task or a series of related tasks.

2. Training accesories—visual, graphic or other instructional supplements which have no training capabilities per se but may be used in a training course in conjunction with specific training aids.

3. Training parts—items of system operational equipment which are used or included in training.

Trainers have received the greatest emphasis in industry primarily because they are costly items. Included in the term trainers are simulators, training devices, training aids and training attachments. Simulators refer to the group of equipment, either simple or relatively complex, which uses mechanical/electrical means to simulate the critical aspects of a particular job, position, or task sequence. The Link trainer used in World War II and more complex flight simulators of today are examples of this type of training equipment. Design of adequate simulation equipment requires a great deal of sophistication about the operational system for which it is to provide simulation. Frequently this type of training equipment can be as complex as the system it is simulating, and can be a very expensive item. In addition, it requires that substantial analytic effort be applied to the original system to determine the most valuable aspects of this system to simulate. Inadequate simulation or oversimulation results not only in low cost-effectiveness indices, but also lower utility of training time. Training devices are items of equipment to be operated by the students which perform one or more very specific operating functions. Typically they do not provide for practice in all aspects of a mission, but are equipment for practicing procedures. As a rule, training aids are instructor-operated devices which facilitate training by auditory, visual, or kinesthetic means. These demonstrate the functional characteristic of operational end items without using the operational equipment. Examples of training aids are animated panels, static and animated overlays, pictorial cutaways, training charts, training films, etc. Training attachments are small pieces of equipment used in conjunction with other training equipment in order to perform a training function. Various visual or auditory attachments to a simulator are examples of this type of training equipment.

Development of training plans are part of the overall system development documentation and have, as their data source, documents provided by the system engineering program already mentioned. Specification of training equipment results from analysis of the training equipment planning information (TEPI). This analysis, while properly a part of the concepts of training, warrants a separate discussion and is presented elsewhere in this chapter.

Report Series Relation

The model presented in this series of reports calls for formulation of training concepts and plans (in a representative way) early in system design in order to demonstrate that it will be possible to carry out the training implied by a candidate system solution. In fact to provide the confidence necessary to proceed with a given course of system development, it may be necessary to create increasingly detailed training concepts and plans without any firm implication that the concepts and plans set forth will constrain the development of the ultimate training program. Not until Function G of the model, is it necessary to formulate firm training concepts and plans in conjunction with determining needs for training materials, trainee selection instruments, job aids, instructor selection and training-plant selection, and for training-program development.

Training Equipment Planning Information (TEPI)

During completion of system development analysis, recommendations are made for equipment to be used for training operators and maintenance personnel in the use of the system. The TEPI provides recommendations for each functional allocation of particular equipment to be used in that training. The training equipment ranges from specific, small training aids to complex, whole mission simulations. The basis for performing analysis, or summary, of training equipment planning information, are the operating and maintenance concepts for the system, QQPRI, task descriptions, performance criteria and other human engineering data, training concepts or preliminary training plans, state of the art, and preliminary training parts list.

An essential precursor to the development of training equipment planning information is complete investigation of the system to obtain personnel allocations and clarification of skills and knowledge required by the developing system. In many cases training equipment identified in TEPI reports may be found as on-the-shelf items. However, as the system under development requires more and more complex interaction among the personnel manning the system, the nature and complexity of training equipment also changes. In some cases, particularly when a great deal of personnel interaction is required to optimize the performance of the system, system training is necessary. In this case, training equipment recommended in the TEPI report may be quite elaborate.

Report Series Relation

If this approach to the development of requirements for training equipment is employed in the course of a development cycle constructed according to the model presented in these reports, TEPI would be employed in Function G. In G it would be important in making the trade-offs among what will be trained, what will be job-aided, and what performances will be selected. As a result of these trade-offs, the training equipment will be called out in terms of the performances to be fostered by means of the equipment; no detailed means would be specified.

Skill

Skill, or skill level, refers to the proficiency level of an individual in an assigned training program or career field. In the Air Force and Navy systems, skill levels refer to orderings of individuals by numerical code in career field proficiency level. Usually given in descriptions of a particular skill or skill level is the rank of the person, the number of years in service (as a range), the training schools the individual should have attended, and the proficiency levels within each of the training schools. Also associated with skill level, are the equipment and systems within which the individual has received training.

This information is used in system development to identify appropriate individuals for manning of the system both in terms of maintenance and operation. As such, it is frequently included in maintenance analysis and training equipment planning information.

Job skills, a related term, refers to the abilities required of personnel in performing various tasks which make up a particular job. These skills include perceptual decision making and manipulative abilities.

Report Series Relation

In this series of reports, measures of goodness of subsystems, component functions, system parts, or any other partition of the system are restricted to those which can be derived from the Quality score which is used to measure total system "goodness." It has not been necessary nor desirable to employ the concept of skill, nor to construct a way of measuring skill in order to measure the goodness of any personnel products. Thus, although we may speak in general of measuring skill, any measure of skill which is commonly used appears to be unrelatable in a systematic and useful way to overall system quality.

XI. PERSONNEL SUBSYSTEM TEST AND EVALUATION

A key concept in the development of a system is that all major subsystems, components within subsystems, and, in fact, the system as a whole, can be and should be exercised for evaluation purposes as many times in the course of development as possible. Such test and evaluation provides constant information about the adequacy of the development cycle as it is proceeding. It can also provide valuable insight into the performance qualities lost or gained by various allocations and trade-offs made in the course of development, as well as providing information in those areas requiring additional development for reaching greatest utility and optimization of men and equipment. As a specific called-for product of the system development, periodic test and evaluation of the personnel system is usually demanded by the sponsor.

Formalized test and evaluation procedures can be usefully implemented at virtually any stage in the development cycle of the system. However, until such time as substantial portions of the system are present in operational form, evaluation can take place only of simulations, mock-ups, or documentation of the system. Consequently, the most comprehensive evaluation and tests of the system and system components are frequently directed to occur during the final stages of the development and acquisition stages of the system.

The topics covered in this chapter consist principally of a discussion of personnel subsystem test and evaluation program and a discussion of system-effectiveness models. The latter topic is included because it provides, on an ongoing basis, a major tool that may be used for constant evaluation of the adequacy of requirement development in the course of system analysis.

Personnel Subsystem Test and Evaluation (PSTE)

System development, as it is commonly practiced today, requires the complex interaction of a number of concurrent activities. One of the major classes of activities is personnel subsystem development. To ensure appropriate development and facilitate the many decision points in the development cycle, all component aspects of the system are frequently tested, evaluated, or otherwise exercised during the course of development. This is particularly true with the personnel subsystem. This test and evaluation takes place during, and immediately subsequent to, the development cycle of a system.

Generally, three time-oriented evaluations take place. The first, concerned only with specific identified subsystems of the system, takes place during the early portion of the development cycle as each component and subsystem is developed. The concern, or focus, of this type of test and evaluation includes:

1. Evaluation of, and refinement of, initial requirements for personnel and training, training equipment and instructors.

2. Evaluation of the human engineering applications to subsystem and component design.

3. Identification of preliminary skill requirements.

4. Evaluation of training equipment developed to that time to determine whether the equipment meets the requirements of performance as called out by system engineering documentation.

After the system has been developed to a point where major subsystems can be integrated and exercised as a system, a second test and evaluation procedure is initiated. The goals of this testing are to:

1. Determine whether the products comply with specifications;

2. Evaluate new design changes before they become incorporated into the production model;

3. Determine the system's capabilities and limitations under actual or simulated conditions;

4. Provide limited training on the developing system;

5. Determine whether the system will in fact meet the requirements of the follow-on system as well as prove adequate for adjacent systems; and

6. Determine the adequacy with which the system can be maintained with minimum outlay of resources in terms of personnel, logistics, and back-up equipment.

The final test and evaluation occurs subsequent to the actual development of the system but prior to the system's inauguration as an operating system. This test is predominantly one of user acceptance and user evaluation, and is, as a rule, conducted solely by the customer agency. In this test, all aspects of the operational system are exercised in an ongoing operational fashion. Objectives of this particular test are:

1. To determine the utility of the system and development of the most effective procedures, techniques and job standards.

2. To identify any deficiencies in the process or procedures of the system.

3. To assess the adequacy of training procedures as they are specified during the development cycle, and as they are implemented during and subsequent to the development of the system.

4. To initiate the system into its ongoing capacity as an operational unit.

While specific points along the development of the system can be identified and associated with implementation of personnel subsystem testing, the personnel subsystem can be tested and evaluated at virtually any stage of the development cycle. Depending on that point in the cycle when the testing is performed, specific goals could be outlined. However, one may identify several general purposes of personnel subsystem test and evaluation that are applicable at any time. One such purpose is that test and evaluation helps ensure that the system can be operated, maintained, and controlled by the personnel who will man it. This has obvious ramifications to the development of not only functions allocation and task development, but also training requirements identification, training equipment and training planning. A second major purpose of PSTE is to identify those areas in the personnel subsystem in which problems may arise and to identify those tasks and procedures in which deficiencies in performance will result in degradation of system effectiveness. A final purpose of the PSTE that may be mentioned here is to establish and evaluate methods, techniques, tools and requirements for the research, development, and test of personnel subsystems.

Report Series Relation

In this series of reports, the purposes of the Personnel Subsystem Test and Evaluation program are achieved by a sequence of four function types identified in the development cycle model. The first of these (H-13 and H-14) are implemented after completion of the training program and are designed to demonstrate the performance capability of the selected, trained, job-aided personnel who are to perform in the operational system. After deficiencies detected by this test have been corrected, the crew is tested in conjunction with the Human Support System (H-15 and H-16). If appropriate, the crew is also tested when it is integrated into the complete local (remote) segment for a test of the segment as a whole (H-17 and H-18). If previous tests have been passed, presumably failures in this test may be attributed to integration problems. The final test in this sequence is a test in which the personnel products are integrated into the total installed system for a test to demonstrate total system capability (H-20). In the model all of these test functions are undertaken in Phase III, the fabrication phase. Taken together they are essentially equivalent to PSTE in that they serve the same overall purpose.

System Effectiveness

The output state of a given system is usually a set of qualities, each of which can be related to the objectives of the system. System effectiveness is a measure of how well these objectives are met and the extent to which elements within the system contribute to the effectiveness. These elements are generally termed accountable factors. In certain cases, a meaningful definition of system effectiveness cannot be accomplished unless the supersystem is considered.

According to the system-effectiveness concept, the relative value of an element within the system is determined by the extent to which it contributes to overall system performance. This permits trade studies by comparing the relative contributions to system performance with relative costs involved. It also requires every element in the system to be expressed in terms meaningful to the overall system performance.

As with many terms discussed in this report, system effectiveness can be given a general definition. However, more precise definition of the term —for it to be used in the context of a particular development system—requires a specification of particular parameters that are measured and included by system-effectiveness models. Thus, the operational definition of the term is found only in particular applications to given systems. One attempt to formalize the procedure of deriving precise parameters for measurement from the more general definition of the term given above was made by the Weapons System Effectiveness Industrial Advisory Committee. For that committee, system effectiveness is defined as the vector of specified figures of merit, where figures of merit are indices which indicate the quality of the system. System quality can be, in this context, a measured physical quality such as payload weight, range or altitude of a vehicle. It may also be a calculated quality based on statistical measures such as mean time to repair, or mean time between failures. Finally, it may be a predicted quality based on measurement and/or simulation. Point availability would be an example of this last predicted quality.

System effectiveness is not an entity in and of itself, but rather an index score representing the relation of a number of variables. The means for expressing this relationship frequently takes the form of a mathematical model. Components of this model are the following:

1. Mission profile—a time line analysis of the sequence of events for a given mission.

2. Mission outcomes—principal events that result from a mission. These outcomes can be distinguished on the continuum of success, partial success, or failure to fulfill the mission. In some respects

these outcomes are parallel to specification of system requirements. Mission outcome statements are made concerning the events resulting from a mission, whereas system requirements statements are made about the need for particular system output states.

3. Functions definition—an identification of and statement about each major function that contributes to achieving the system output.

4. Accountable factors identification—those specific factors known to determine figures of merit. This requires exploitation of all assumptions made in regard to factors influencing figures of merit. Categories within which accountable factors may be identified are, system hardware descriptions, survivability, vulnerability, personnel, support equipment, and system interfaces.

System effectiveness is then estimated from a model combining the information developed in the above areas. The model serves as a probabilistic representation of events which may occur during a system mission. It relates the possible events to levels of performance adequacy which may be expected for the mission.

Construction of the model is generally described in four steps:

1. State description;
2. Determination of availability vector;
3. Determination of dependability matrix; and
4. Determination of capability matrix.

Description of the significantly different system states in which the mission may be carried out is the first step. States are distinguishable conditions of the system produced by functions, processes, or events occurring before and during the mission. The system makes transitions from state to state during a mission. As a result of timeline analysis, the mission is split into a number of discrete time intervals during which different functions are being performed. During each discrete time interval a set of significant states, appropriate to the function being performed during that interval, may be identified.

Relating accountable factors to the probabilities of each set of significant states is the next step. The array of probabilities is called the availability vector. The relationship between the array of state probabilities and accountability factors is identified for each succeeding time interval. These probabilities are dependent on, or conditional to, an effective state during previous time intervals. The array of conditional probabilities are called the dependability matrices.

Given the system conditions during the mission, the final step is the construction of an array of measures of the ability of the system to achieve mission objectives. This is the capability matrix. This matrix specifically accounts for the performance spectrum of the system. Each element of the matrix is an expected figure of merit conditional on performing the system mission in a given effective state.

The nature of information serving as inputs to the model, and the decisions to be made on the basis of model outputs determine, in large part, the structure of the model. The models may also be subdivided by level of system evaluation desired, such as system, subsystems, equipment, or smaller components. Level of evaluation is contingent on the objective of the particular evaluation and available information.

Because of the nature of quantification required by model construction, it is easier to include parameters of effectiveness relatable to equipment components rather than personnel components of the system. Within the context of development systems whose goals are primarily scientific rather than military, the personnel subsystem components included in the model are usually those of crew safety and adequacy of data return. All aspects of operational and maintenance activities performed by personnel associated with the system are related to those two factors. The choice of these factors is not necessarily a poor one. In systems designed to acquire scientific data, the contribution of the crew to assist in obtaining this state is of critical value to the overall effectiveness of the system. In the case of manned spaceflight—given the political and psychological attitude of the public—crew safety is an equally important factor.

Clearly, it would be possible to subdivide each of these factors into a number of component parameters. However, since such subdivision is difficult and time-consuming, and since in most development systems the two personnel subsystem factors are given equal weights in terms of contribution to the overall system-effectiveness model, further division of these factors is rarely performed in a systematic fashion. Since the greatest utility in systems analysis is achieved by constant relation of functional breakdowns to more and more specific indicies of system effectiveness, this failure to provide specific system-effectiveness parameters for personnel subsystem factors is an inadequacy in current methodology.

Report Series Relation

The term system effectiveness is not used in these reports. However, many of the concepts implied by the term are found in the meaning of the Need Satisfaction and Quality scores. These scores are completely discussed in Report I of this series. For the reader's convenience, a brief review of the scores is presented here.

Need Satisfaction Formula Score. —Development of a system is initiated by the customer's needs. Expression of that need may be traced to some dissatisfaction about the customer's system. (N. b. The customer's system referred to here is the follow-on or supersystem which the development system is proposed to serve.) When the customer's problem has been identified, it may be related to a set of measures that will later permit quantification of how well, or to what degree, the problem has been alleviated. The formula expressing these measures is the Need Satisfaction Formula. Put another way, a Need Satisfaction score formula tells how any proposed way of solving the problem will be evaluated. For example, any proposed solution which completely fails to reduce the problem might be assigned a Need Satisfaction score of zero; any proposed solution which completely solves the problem might be assigned a Need Satisfaction score of one. The formula for measuring need satisfaction (problem reduction) would assign numbers between zero and one to reflect the "goodness" of less than perfect solutions.

A Need Satisfaction score formula is, of course, a specially devised act of measurement. By obtaining the customer's concurrence in its formulation, a public method for measuring the goodness of alternative ways of solving his system problem is established. Because the formula is one for measuring effects in his system, the formula is completely unbiased with respect to solution methods and may be employed to evaluate any candidate.

It is also useful to talk about a target Need Satisfaction score. The implication of a target score is that any candidate solution for the problem which yields a lesser score will be completely unacceptable. Taken together, a Need Satisfaction score formula and a target score provide a basis for a clear understanding between a customer and someone who is attempting to solve his problem with respect to the objective of the problem-solving effort. It is worth restating that a Need Satisfaction score formula is never tailored to the measurement of a particular method of solving the problem of the customer; it is always unbiased so that it may be used to evaluate any proposed solution.

Quality Score. —In these reports, we are concerned with needs or problems which require complex systems for their solution. This report is not specifically designed to be useful in those cases in which there is a simple solution to the problem identified by a Need Satisfaction score formula.

We are concerned here with the case in which we must build a complex system, A, in order to achieve a target Need Satisfaction score in its follow-on system, B. In general, if system A must be complex and costly and can be justified, then the problem in its follow-on system must be one of significant importance to society.

Given a Need Satisfaction score formula and a target score for system B, we have a criterion for the success of system A, but we do not have a demarcation of its output boundary. A way to make such a demarcation must be provided.

One way to obtain an identification of the output of system A is to model system B in such ways that one may explore the effects of various hypothesized inputs to system B upon its Need Satisfaction score. The result of such an exploration can be the development of a formula for measuring a hypothetical output of system A in such a way that the resulting Need Satisfaction score can be predicted purely on the basis of output measurement (that is, measurement of the hypothesized input to system B).

We will call a formula for measuring the output of system A in such a manner that the resulting Need Satisfaction score can be predicted, a Quality score formula. It will be useful to think of Quality scores which result from the application of this act of measurement as falling in the interval zero to one, in the same manner as Need Satisfaction scores. Thus, a Quality score of zero will correspond to a Need Satisfaction score of zero and a Quality score of one will correspond to a Need Satisfaction score of one. By means of the device of the Quality score formula, we provide ourselves with a way of identifying objectively the output that we need from system A without entangling ourselves in the inner workings of system B, and without necessitating the use of the Need Satisfaction score. Thus, there will be a target Quality score which corresponds to the target Need Satisfaction score and which may establish the lower boundary of acceptable output of system A. We may then say that system A may be implemented in any manner that will yield a Quality score greater than or equal to the given target Quality score.

For complex systems, the makeup of a Quality score formula can itself be very complex. Whatever its makeup, it is clear that it must be determined by consideration of system B and not by consideration of system A means, for system A will not exist at the time of Quality score formulation. Inasmuch as a Quality score formula is constructed on the basis of an analysis of system B, there is no single prescription for what it must include; it must be tailored to the system B at hand. The best that can be said about the content of a Quality score formula is that it will most likely include provision for the measurement of a number of factors and provision for combining the obtained factor scores into a single overall Quality score. Some of the factors which must be taken into account will include: the output state, the time when the output must first be made available, the life required of system A, the dependence of the output of system A on signals from system B, the probability of output required, and the conditions of use under which the output must be provided.

In practice, it may be very difficult or even impossible to prepare a Quality score formula of the type described here and to obtain customer agreement upon it. Nevertheless, the eventual test of any implementation of system A will require measurement according to a formula. It can be seen that whatever formula is used for measuring system A, it will be used in exactly the same sense as the Quality score formula described here.

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XII. BASIC DESIGN DATA

This chapter is concerned with a discussion about basic design data. The chapter has not been divided into topic headings for several reasons. The first and foremost reason is that basic design data is, by its very nature, a singular topic. Further division of this topic could only be by type of data involved. To do this would be to replicate much of the information appearing in earlier chapters of this report. A second reason is that basic design data refers to the large body of data supporting system development, and the requirements for management, control and organization of the data—distinguishing subcategories or topics of basic design data would in a sense be violating the integrating function performed by the topic itself.

While the discussion below specifies the nature and definition of basic design data primarily with respect to the personnel subsystem, the term can be broadly applied to the base data used throughout the system in its development. As such, these data would include the following:

1. System requirements analysis data;
2. Specification criteria data;
3. Personnel requirements data;
4. Training and training equipment planning data;
5. Engineering drawings;
6. Procedural report data;
7. Ancillary data requirements (test program data, health and safety data, calibration data, etc.).

From this list it may be seen that only some of the data included in a general basic data program would be concerned with the personnel subsystem. Those data that do fall within that class are discussed in the following section as well as in earlier portions of this report.

Basic Data

The basic data program is the Personnel Subsystem design portion of PSD. If the basic data program starts after personnel are assigned as means for individual functions, the program may be considered to be specific to the PSD sequence. If the basic data program includes the initial breakdown of the abstract system into its functional components, then parts of the basic data program are considered to be a subsystems function which is not specific to PSD.

The term "basic data" is used since the performance requirements are presented to other personnel in the development sequence (Training Department, T.O. Department, etc.) in the form of data. The data are considered to be basic since the performance requirements are basic to all means of developing the necessary performance capability, such as equipment, training, T.O. or job guides, i.e., all of the means for implementing a given function must be oriented towards the same requirements. If physical means (as opposed to functional means) are not included (except for personnel means) the output from the basic data program may be regarded as the means of communicating performance requirements, functional means, and detailed description of personnel performances.

Quite frequently, the "data" portion of the basic data program is emphasized and little attention is given to the analytical processes required to provide the data. In so doing, the emphasis is placed on a central source of data gathered by one group of personnel to minimize the interaction of different personnel with the design engineers. This is an excellent concept but does not cover the problem of who should specify personnel performance requirements. Concentration on the data portion of the program generally results in the equipment designers specifying personnel performances, i.e., analysis of the system is implemented by the engineers and the human factors specialists merely document the results. Too frequently an engineer tends to consider personnel not as an available means with a given capability, but rather as a necessary evil. Thus the means selected are frequently not optimum when evaluated in terms of the requirements for the function.

There are several types of data usually provided within the basic data package. As a rule these data are of the following types:

1. System functional-flow diagrams—identifies and shows the sequence of all system functions and activities programmed for the operational system.

2. Operation/Maintenance activities analysis—translates system functions in terms of equipment and personnel required in the performance of each identified system activity. The data are given in tabular form, listing derived equipment and personnel performance characteristics by system function.

3. Performance standards (proficiency) analysis—further reduction and detailed specification at the input/output level of the performance (by personnel) described in the analysis referred to above. Included in this type of data are malfunction isolation/emergency procedures data which detail the procedures employed by personnel upon indication of malfunction or hazard condition.

To achieve optimum utilization of basic data, a basic data organization model may be developed. This model organizes all data produced by or relevant to the development of personnel subsystems for the particular system. The principal objective of the basic data organizational model is to organize system data so that individuals generating basic data materials know where to store them (or how to designate them properly for storage), and the people needing these materials know where to find them. It is organized so that all basic data for a particular function activity are readily located in individual pockets.

Inherent in some data organization models is a designator-locator system designed primarily to facilitate storage and retrieval of basic data by providing a unique designation for system data references at various levels of specificity. In general, this designator-locator system is a set of coded designators for equipment and function partitions. The symbology adopted for coding these two basic designator subsets (i.e., equipment designators and function designators), provides for the identification of system equipment down to the level of modules (principal subassemblies of line replaceable units) and for identification of system functions down to location and equipment-specific activities and tasks. Through appropriate combinations of equipment and function designators, unique designators are available for each type of basic data. This system is also used to identify tasks and task elements associated with an activity through the use of a third subset of designators.

Report Series Relation

If one considers the stabilized design decisions made in the course of system development to be cumulated into a basic data pool, then there will always be a source of firm data to be employed by all activities in a system development cycle. The term basic data as employed by human factors and biotechnological personnel typically refers to that portion of the basic data pool which is specifically related to personnel products. This subset of data is not specifically called out in the model developed in these reports.

XIII. RESEARCH IMPLICATIONS

The manner in which the system analyst deals with the phenomena, events and data in systems analysis is reflected to a large degree by the terms he employs to label the events, data, and analysis he performs. It should be evident to the reader that many of the terms employed in systems analysis are employed without precise usage or definition. The proliferation of terms, concepts and analytic techniques reflects the increased interest in and necessity for personnel subsystem analysis. However, it would be erroneous to assume that the terms, concepts and analyses have necessarily a one-to-one relationship. A term may be employed by a particular user to mean a relatively specific concept or analysis. As the term achieves wider use, the meaning of the term becomes more and more vague until finally the term has very little precise meaning to a majority of the system analysts. Consequently, a new term or a modified old one is substituted, again with an initially precise definition, and, as it grows in more general use, it becomes a vaguer and vaguer one.

The result is that in current use there is a variety of terms that have no definite referent. Further, reflection on those terms presented in this report illustrates that it is sometimes very difficult to distinguish between two terms having in fact the same general reference. Too often the analyst is compelled to devise an idiosyncratic term, primarily because he cannot understand nor distinguish among the more popularly used terms. Too often, the analyst reads through a description of a concept only to find that he is quite familiar with the concepts being presented but is totally unfamiliar with the terms used to describe or label the concept or set of concepts. Depending on his inventiveness and tolerance, he may, in his use of the concepts, either use the unfamiliar terminology and assume that it is general in the community, continue to use his own, perhaps older, terminology, or decide to invent a new term or set of terms to unite both the old and the new and serving only to create more reader confusion.

With respect to the terms presented in this report, both the author and the readers are required to distinguish among a set of terms that have wide popular usage but not necessarily a precise public meaning. The aerospace industry analyst has shown a great willingness to work within precisely defined frameworks of system development. They have thus far, however, been resistant to the kinds of structures so far proposed. This reflects, not a lack of cooperation so much as it does an inability to operate consistently and meaningfully within the frameworks thus far provided. It is suggested, on the basis of this report in particular, that the reason for the analyst's inability to operate successfully within system development frameworks usually imposed, is that the terms and concepts with which he is compelled to operate are not precisely defined nor presented in a way which would permit him ready access to the meanings of the terms and concepts.

In order for system development of complex man-machine systems to derive the greatest utility from the activities of systems analysis in general, and human factors (or biotechnology) in particular, requires a systemization and precision of definition so far not present. The needs of this community may be seen to be made up of three major components.

1. A set of terms and concepts precisely defined so that they may be uniquely and clearly distinguished each from the other. Where two or three terms may be found in popular usage that refer to the same general area or topic, a choice should be made of just one of them. This one should then be defined to a degree that permits ready distinction of the referent of this term with all other terms. By precisely defining terminology, it is possible to develop internally consistent and logical concepts, and from these concepts, tools and techniques to implement effective system development. When the terminology itself is vague, or heavily overlapping in referent, then the concepts derived from these terms usually are also vague.

2. Identify ways in which the terms and concepts can best be presented didactically. Identification and definition of terms and concepts in a highly precise, logical and internally consistent fashion is in and of itself insufficient to obviate the confusion and ambiguity present in the nomenclature-related problems of systems analysis. The scheme must, in its entirety, be made public information to the aerospace community. In order to do that requires

more than just publishing the terms and their definition. It is necessary that these terms, concepts, and techniques be presented to the community in such a way as to facilitate the community's understanding and comprehension. A particular idea might be quite logically and precisely defined and explained, but unless this explanation and definition is presented in such a way to make it meaningful to the reader, the information remains private rather than public. The need in system analysis of development systems is for a set of <u>public</u> terms and concepts. Studies should be undertaken to determine the potential techniques for most effectively presenting the identified terms and concepts. Potential techniques may be through strip film, through various audiovisual techniques, through motion pictures, or through programmed instructional manuals. While it is impossible at this time to determine which among those techniques would be most effective in presentation of the information, it is quite possible to say now that the standard technique of presenting these terms in the form of a manual is not always effective. The popular terms are presented currently in a variety of manuals, none of which have proven to be very effective in teaching the user the requisite information.

3. When a method or set of methods has been identified as the most effective means for presenting the terms and concepts, this should be made into a formal package and presented to all individuals, companies, and agencies who would have need for these products.

Any attempt to provide such a package would not be easily accomplished—the methodology is not simple nor is it self-evident. However, one can now suggest the first steps to be taken.

1. <u>Identify the community needs</u>. —The biotechnology fields should be investigated to determine the scope and nature of their needs for terminology, concepts, and structure. Particular emphasis should be directed toward the potential problems facing the development of an organized terminology. Two such problems identifiable now are user acceptance and provision for the dynamic nature of the terminology. The first mentioned problem, user acceptance, must be solved completely before any major resources are expended to develop a terminology. The user—the system analyst—must accept the terms

and their implicit structures for the structure to have any utility. It is essential to determine the parameters of this acceptability at the very beginning. The second problem is also critical. Techniques must be developed to permit the biotechnological disciplines to retain the dynamic growth of concepts without reflecting this change by the addition of new terms rather than by continuous changes of terminology definitions.

2. Survey other disciplines. —When the need structure of biotechnology has been identified, other scientific and technical fields should be studied. The purpose of the study should be to reveal whether the other fields have similar terminology problems and if they do not, as chemistry, for example, does not seem to, determine what frameworks, structures, etc., have promoted the consistent and stable nomenclature. A comparison of discipline needs will result in identification of possible solutions that may be viable in biotechnology.

The results of these two steps will be a firm basis for continued solution of the problem. Particular outputs should include:

1. Characteristics of the terms and syntax. A terminological tool should have to meet the needs of the discipline.

2. Identification of techniques for promoting acceptance of a terminological tool.

3. A set of candidate approaches which can be ordered in terms of the need satisfaction potential identified in 1 and 2 above.

Performance of the above steps will not solve the whole issue, but will result in data from which the steps necessary for completion can be derived and detailed.

Serendipity Associates
Chatsworth, California, October, 1966

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